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SOLAR PV IN AFRICA: COSTS AND MARKETS

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

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All data in this report is indicative and is not necessarily representative of all projects in Africa, results should be interpreted with caution.

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EXECUTIVE SUMMARY

Africa has abundant renewable energy resources. Traditionally reliant on hydropower, the continent is increasingly turning to solar photovoltaics (PV) to bolster energy security and support rapid economic growth in a sustainable manner. Solar PV module prices have fallen by 80% since the end of 2009, and PV increasingly offers an economic solution for new electricity generation and for meeting energy service demands, both on- and off-grid.

Africa is endowed with significant renewable resources of all forms. Hydropower has traditionally been the largest renewable power generation source, contributing 97 terawatt-hours (TWh) of hydropower generation in 2013 (15% of total generation). However, with recent cost reductions for solar PV, concentrating solar power (CSP) and wind power, this could change rapidly. Solar PV module prices have fallen rapidly since the end of 2009, to between USD 0.52 and USD 0.72/watt (W) in 2015.[1] At the same time, balance of system costs also have declined. As a result, the global weighted average cost of utility-scale solar PV fell by 62% between 2009 and 2015 and could decline by 57% from 2015 levels by 2025.

Globally, new capacity additions of solar PV have increased six-fold from around 8 gigawatts (GW) in 2009 to around 47 GW in 2015. This growth has largely bypassed Africa, despite solar irradiation in African countries being 52% to 117% higher than in Germany. However, technology improvements and lower costs have spurred local and social entrepreneurs in the solar home system (SHS) market[2] and in stand-alone mini-grid markets, while in the utility-scale sector – systems larger than 1 megawatt (MW) – support policies are beginning to bear fruit. New capacity additions of solar PV in Africa in 2014 exceeded 800 MW, more than doubling the continent's cumulative installed PV capacity. This was followed by additions of 750 MW in 2015. By 2030, in IRENA's REmap analysis of a doubling of the share of renewable energy globally, Africa could be home to more than 70 GW of solar PV capacity.

With recent cost reductions, solar PV now offers a rapid, cost-effective pathway to providing modern energy services to the approximately 600 million Africans who lack access to electricity and utility-scale electricity for the grid.

Solar PV is a highly modular solution, both on-grid and off-grid. It can provide lighting and electricity to a single home off-grid, can be incorporated into mini-grids that can scale from several kilowatts (kW) to many MW, and at utility-scale can achieve higher economies of scale. Facilitated by and pulled by the growth of "mobile money"[3], small 20-100 W SHS can be purchased on pay-as-you-go schemes, and provide modern energy services for lighting, mobile phone charging and other small appliances that are higher quality than the equivalent (*e.g.,* kerosene lanterns), at a similar, or lower, monthly cost. At the same time, auctions and tenders for utility-scale solar PV in North Africa and South Africa have shown that solar PV can be a cost-effective large-scale source of new capacity. There also is increasing interest in the use of solar PV in mini-grids, both isolated and grid-connected, which can be an attractive option to reduce diesel costs or to go 100% diesel free.

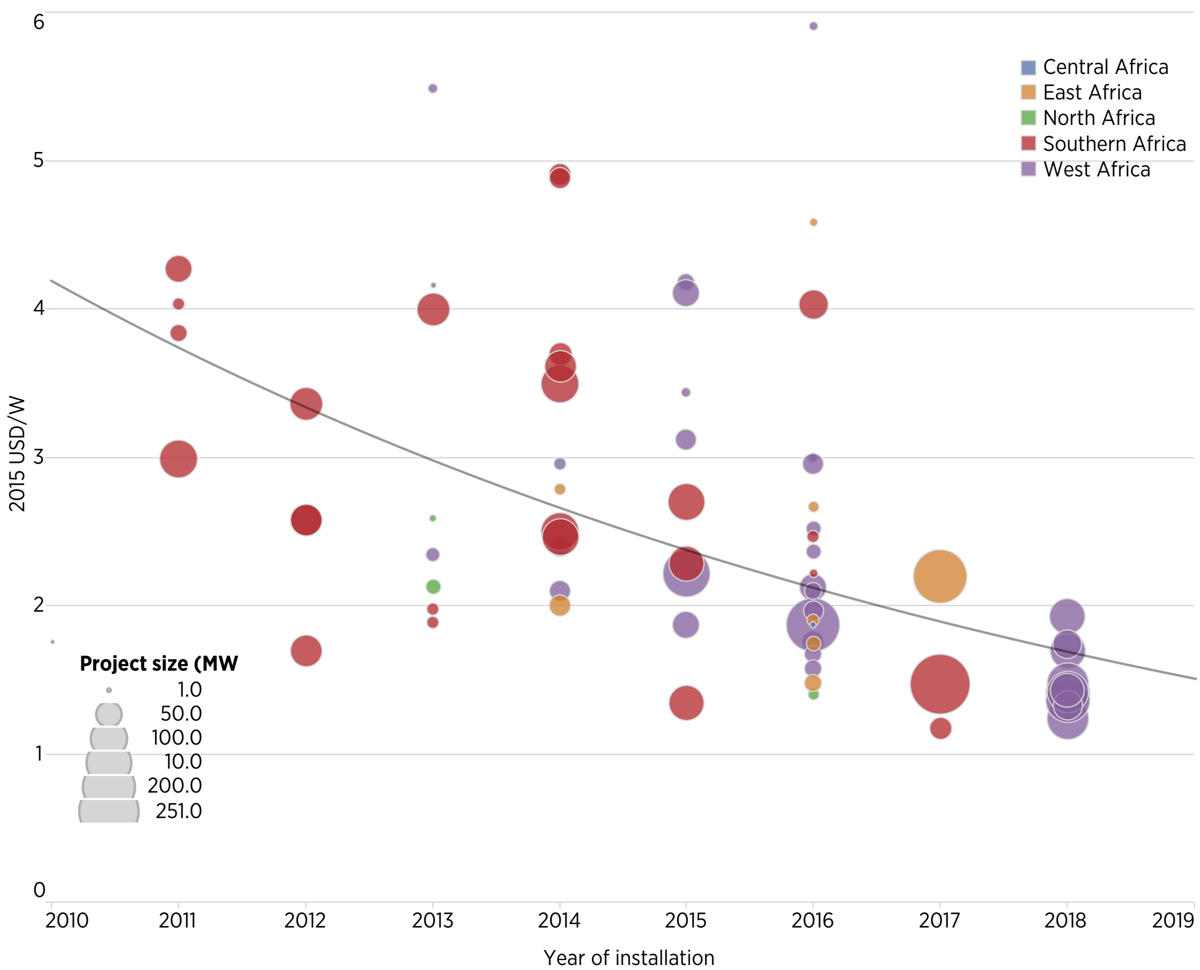
Solar PV has another advantage. Project lead times are among the shortest of any power generation technology and can be deployed much more rapidly than many other generation options. Given the pressing need across Africa to address the low rates of access to electricity and poor-quality electricity supply (*e.g.*, frequent blackouts and brownouts), the ability to rapidly scale up solar PV is a significant benefit.

1 All financial values in this report are expressed in real 2015 USD values, that is, taking into account inflation.

2 This report does not cover the so-called solar pico lighting solutions of rechargeable solar lanterns with integrated or connectable very small solar cells.

3 Banking services provided via mobile phones.

Figure ES 1: Operating and proposed utility-scale solar PV project installed costs in Africa, 2011-2018



Note: Each circle represents an individual project. The centre of the cricle represents the value on the Y axis and the diameter of the cricle the size of the project.

Many of the latest proposed utility-scale solar PV projects are targeting competitive installed cost levels that are comparable to today's lowest-cost projects.[4] This is a very positive signal, given the nascent market for solar PV in Africa and the challenging business environment for infrastructure projects in many African countries.

On-grid commissioned and planned utility-scale solar PV projects between 2014 and 2018 in Africa range from around USD 1.2 to USD 4.9/W (USD 1 200 to 4 900/kW). Although Africa is currently home to a very small set of utility-scale solar PV projects, costs have been declining over time. The cost range was between USD 3.4 and USD 6.9/W in 2012, declining to USD 2.4 to USD 5.5/W in 2013 and to USD 2 to USD 4.9/W in 2014 (Figure ES 1). For 2015 to 2016, the cost range is anticipated to be between USD 1.3/W and USD 4.1/W. If the projects targeting USD 1.3/W in installed costs can be built to budget, this would represent a very competitive level for Africa, given the estimated worldwide weighted average for utility-scale projects of USD 1.8/W in 2015.

South Africa, with its strong civil engineering sector and large renewable independent power producer (IPP) programme (which provides investor certainty), has the lowest installed cost for an operating solar PV plant (around USD 1.4/W for the best project) on the continent for the data available. Other countries

4 In this report, the term "cost structures" refers to the individual cost components that contribute to the total installed costs of a solar PV system (*e.g.*, modules, inverters, racking and mounting, cabling, installation costs, permitting fees, system design costs, etc.). See the full report for a detailed description of the cost categories analysed.

are targeting cost structures in the range of USD 1.5 to USD 2.5/W in 2016. Given the challenges of doing business in some parts of Africa – and the fact that these will be either the first solar PV plant in a country, or one of just a handful – this cost range is reasonably competitive. Project announcements in 2016 that are targeting commissioning dates in 2018 (with perhaps some projects online in late 2017) are targeting a competitive total installed cost range of USD 1.2 to USD 1.9/W.

Off-grid utility-scale projects (> 1 MW) are relatively uncommon, with little data available for Africa. In many cases these represent the bundling of a number of smaller solar PV plants into a single strategic project. For instance, data for one project of rural electrification of schools and hospitals suggests costs of USD 6.8/W for 1.9 MW in total. Another project targets costs of USD 4.6/W for 4 MW of electrification projects. However, without specifying the total number of systems involved, it is not possible to analyse the relative economies of scale that these projects should expect. As a result, it is difficult to come to any conclusion about the competiveness of the installed cost structure for these projects. However, there are off-grid projects in the 1 to 5 MW range that are targeting costs below USD 2/W for 2016 and beyond, which is relatively competitive for this scale in the African context.

Mini-grids utilising solar PV are potentially an attractive electrification option. The installed costs of solar PV for mini-grids span a wide range, but recent and planned projects show examples of competitive cost structures.

Isolated mini-grids offer the potential to electrify entire communities in a single project, as well as providing flexibility to scale and interconnect with the grid at a later date. Existing, grid-connected mini-grids (in government, education or hospital complexes, mining or business activities) also represent an opportunity for solar PV to reduce operating costs and lock in prices.[5] Their scale is typically modest and can range from as low as 8 kW to 10 MW in Africa, although large cornerstone customers like mining operations offer the opportunity to have even larger solar PV systems (*e.g.*, the planned 40 MW solar PV plant at the Deep South Mine in South Africa).

With the fall in solar PV costs, solar PV mini-grids offer important economic opportunities today as either the sole source of generation or in hybrid configuration with other generation sources. Stand-alone solar PV mini-grids or solar PV-hybrid mini-grids have installed costs in Africa ranging from USD 1.9 to USD 5.9/W for systems greater than 200 kW. Solar PV mini-grids that came online in 2012 or earlier have higher costs.

The rapid growth in the market for solar home systems is being driven by lower system costs and innovative new business models. Yet Africa's systems, typically under 100 W, are tiny compared to their counterparts in developed countries and require batteries and charge controllers to ensure stable output. As a result they have higher costs per kilowatt.[6]

The average residential solar PV system in OECD countries has a capacity of 3 to 5 kW. SHS in Africa can be 60 to 250 times smaller, with a typical capacity of 20 to 100 W. In addition to having higher costs per watt due to their small size, these systems need to incorporate batteries and charge controllers. They also may include lights and appliances (*e.g.*, radios, phone charging ports) which raise costs further. These small SHS, with their integrated lighting and appliances, and "plug-and-play" nature, more closely resemble consumer electronic products than residential solar PV systems in the OECD.

5 Mini-grids can rely solely on a single source for generation, such as solar PV, and utilise batteries to ensure that demand is met whenever needed, or during desired periods outside peak solar irradiation, depending on the economics of storage for the site and the users' needs. Alternatively, the mini-grid can rely on multiple generation sources, the so-called hybrid system, which could include mini-hydro, wind and/or diesel, etc.

6 Assuming a 1 to 10 kW system in developed countries.

Typical costs for sub-1 kW SHS systems, which represent the vast majority of SHS sold in Africa, range from USD 4 to USD 16/W, with most systems between USD 4 and USD 11.3/W. There is a wide range of costs for the battery and charge controllers for sub-1 kW systems, from USD 2.5 to USD 6.8/W. The system cost, excluding the battery and charge controller, ranges from a low of USD 1.8/W to a high of USD 13.9/W. These systems in the dataset are based on direct current (DC) and avoid the need for an inverter. Alternating current (AC) systems in this small-size segment have higher average costs.

For larger SHS systems with capacities greater than 1 kW, more recent projects have seen costs within the range of USD 2.5 to USD 7/W, although a number of projects or programmes exhibit higher cost structures, in the range of USD 8.3 to USD 17/W. The battery and charge controller account for between USD 0.5 and USD 6.3/W and on average account for 31% of total installed costs. The lights, fittings and associated materials for these larger SHS are more systematically reported than for the sub-1 kW systems; they account for between 10% and 40% of the total installed costs and average one-fifth of total installed costs. Importantly, falling costs in highly efficient LED (light-emitting diode) bulbs have led to their widespread use in SHS, thereby reducing PV system size and battery requirements for the same lighting service.

Solar home systems in Africa are providing better-quality energy services at the same or lower cost as poor-quality lighting from kerosene lanterns in off-grid situations. Their use, as well as that of solar lanterns, is growing rapidly.

The falling prices of solar PV modules have made SHS an economic alternative for the 600 million Africans without a grid connection, for lighting and basic electrical services. For example, Kenya has seen rapid, market-based growth in SHS, with the number of households using SHS doubling or tripling between 2010 and 2014. In Africa, competitive business models exist that provide better-quality energy services to those using traditional energy sources, even when their monthly expenditure is as low as USD 2 per month for lighting (IFC, 2012). The data for sub-1 kW SHS collected for this report translate into annual costs of USD 56 to USD 214/year, assuming a 5% real cost of capital, a six-year life and one battery replacement.[7] Given estimated annual expenditures today for off-grid lighting and mobile phone charging of between USD 84 per year in Ethiopia and USD 270 per year in Mauritania, SHS can represent a very economical solution (Figure ES 2).

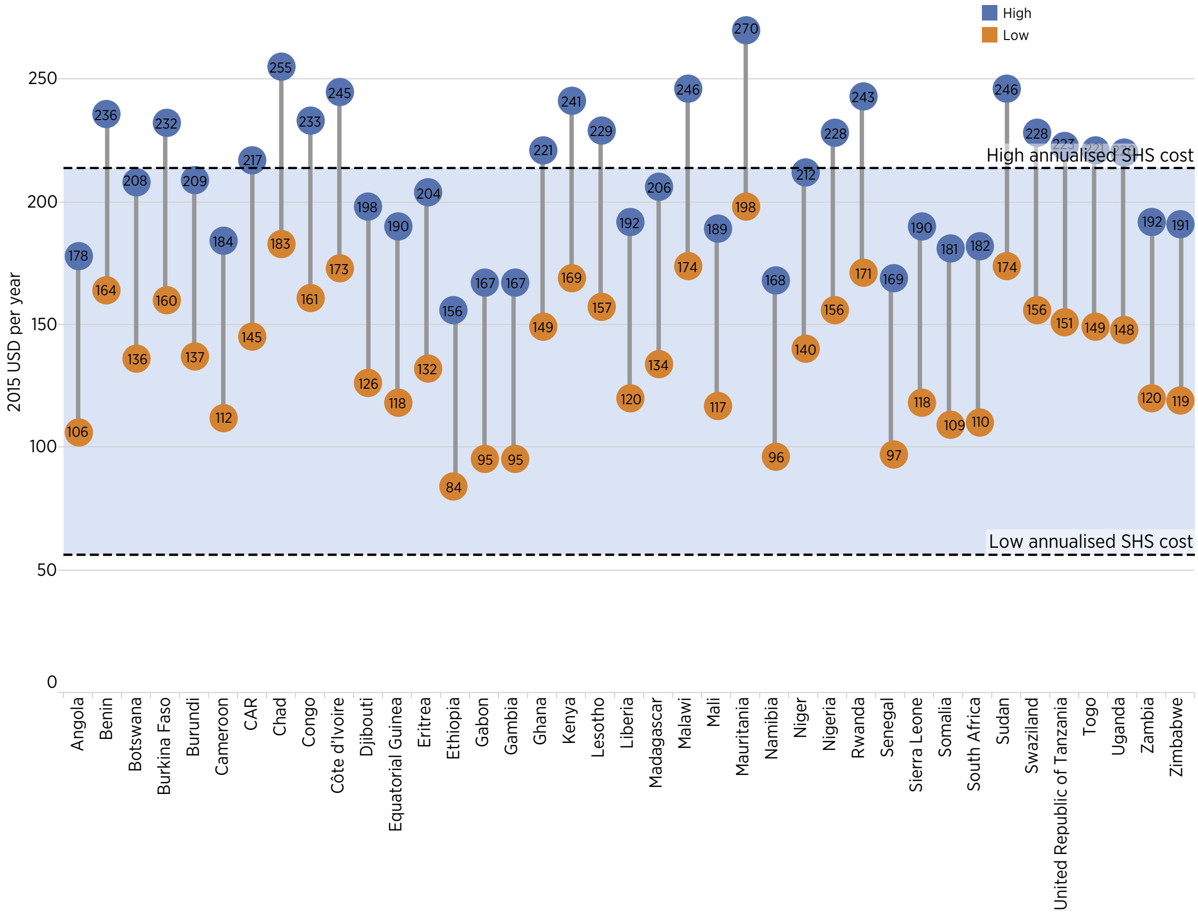
This is before taking into account any reduced transportation costs for trips dedicated to mobile phone charging, which can amount to USD 25 per month in some cases. It also does not take into account the improvement in the quality of energy services provided by SHS using LED lights. For instance, a 2 W LED light will produce around 380-400 lumens of light compared to 8-40 lumens for a kerosene wick lamp. The price per unit of useful light provided by SHS can be one-third to one-hundredth that of the equivalent light from a kerosene wick lamp.

Current solar home systems rely mostly on deep-cycle lead-acid batteries to keep costs down, although lithium-ion batteries are beginning to appear on the market. Battery and charge controller costs currently account for around one-third of total solar home system costs in Africa.

Deep-cycle lead-acid batteries are a proven, relatively cheap electricity storage solution. For the data available for sub-1 kW SHS in Africa, average costs are around USD 2/Amp-hour (Ah) for battery storage capacities of 20 Ah to 220 Ah. This translates into costs of USD 2.1 and USD 6.8/W for the battery and charge controllers, depending on the battery and SHS size combination.

7 For the main components, excluding the battery, this is a conservative assumption but reflects the "consumer electronics" nature of these small SHS products.

Figure ES 2: Annual off-grid household expenditure on lighting and mobile phone charging compared to SHS (< 1 kW) annualised costs, by country in 2015



Note: The blue band represents the range of annualised SHS costs, while the circles represent the high and low annual expenditures of off-grid households for lighting (e.g., kerosene, batteries, candles, etc.) and mobile phone charging.

A drawback of deep-cycle lead-acid batteries is that even if they are carefully managed, they have expected lifetimes of as little as three years, much shorter than that of the other PV system components. Well-managed lead-acid batteries (*e.g.*, limiting their depth of discharge to 20%) may last five years, but the low depth of discharge means that more storage is needed for the same usable electricity. Lithium-ion batteries provide much improved performance (number of cycles) and can support a depth of discharge of 80%. The challenge they face is that they have much higher costs today than lead-acid batteries. However, because of the higher depth of discharge – which reduces the total storage needs compared to lead-acid batteries – and the larger number of cycles possible, depending on the specifics of the PV system and user requirements they already may make economic sense in some cases. Their higher initial costs are a real barrier in the African market, however, and their penetration is currently low. This is expected to change as Lithium-ion battery costs continue to fall rapidly, while lead-acid batteries are a mature technology with little further cost reduction potential.

Cost reduction opportunities for solar home systems exist for the core hardware components of modules and batteries, but also for the balance of system, including all non-hardware, costs. For mini-grids, the challenges are more varied given the multi-stakeholder engagement required, and project development costs dominate the total cost reduction opportunities.

For SHS with a capacity of 1 kW or more, most of the cost reduction opportunities arise from the hardware. Solar PV module cost reduction opportunities account for 14.5% to 17% of the cost reduction potential, batteries from 11% to 21%, the charge controllers from 11% to 22%, other hardware and lamps from 29% to 36%, and soft costs and all other costs from 18% to 21% of the total cost reduction potential for existing systems.

In contrast, for stand-alone mini-grids, soft costs account for 38% of the cost reduction potential, compared to the average in Africa in the IRENA database. Batteries account for 27%, the solar PV module for 20%, the inverter for 7%, wiring and cabling for 5% and mounting and racking for 4% of the total cost reduction potential, relative to best practice costs of USD 2.4/W in Africa.

Solar PV cost data in Africa are not systematically collected or made available to policy makers, resulting in difficulties in setting realistic policy support levels that are efficient and effective.

The collection of representative real-world project costs in Africa is extremely challenging due to the small scale and fragmented nature of the industry in Africa, as well as confidentiality issues. IRENA's dataset is the largest and most comprehensive available to the best of our knowledge. However, data quality and coverage are highly variable, and collecting data on cost breakdowns is extremely difficult. This makes data analysis time-consuming and sometimes limits the conclusions that can be drawn. Systematic cost data collection and comparison is not the norm in Africa meaning that there is often a lack of information on costs and their evolution over time.

A co-ordinated effort to collect the installed costs of solar PV in Africa, across all market segments, is required to improve policy making and to share experiences among countries and regions. This will improve the efficiency of policy support and accelerate deployment, by targeting efficient cost structures in new markets.

This effort to collect better cost data shoud ideally:

- Include a standardised cost data collection categorisation that is agreed upon and implemented by stakeholders, to facilitate the comparison of costs within programmes and between programmes and countries.

- Include governments, international development organisations, regulatory authorities, development banks and multilateral lending institutions and others that provide public financing or other financial assistance to renewable energy projects – including solar PV, but also other energy technologies. These stakeholders will need to systematically collect, on a standardised basis, cost and performance data on the technologies they are supporting.

- Identify a neutral third party to collate and pool the data and make it publicly available (safeguarding unit record confidentiality where necessary), to ensure market efficiency (transparency on costs) and to allow for the evaluation of cost trends and differentials among countries.

- Encourage greater co-ordination in the provision of support to renewables projects in Africa, including information sharing on costs and trends. There is a clear role for donors and organisations that are active in energy sector assistance (*e.g.*, the World Bank, GIZ, African Development Bank (AfDB), etc.) in initiating and driving forward this process through a dedicated multi-year project.

IRENA is ready to help its member states in Africa, and stakeholders providing assistance (*e.g.*, the World Bank, GIZ, AfDB, etc.), to develop a standardised methodology for the collection and dissemination of renewable project cost data and performance, as well as being the neutral, third-party repository for these data.

The IRENA Renewable Costing Alliance could be one vehicle to co-ordinate this activity. It would provide a platform for stakeholders to exchange data and lessons learned, and to identify opportunities for collaboration to reduce duplication of effort. It would be most efficient if this activity was integrated into an existing partnership programme in Africa, with established contacts with stakeholders and an ongoing programme specific to the energy sector (*e.g.*, Africa-EU Energy Partnership, Power Africa, etc.).

The drivers of the current, wide variation in costs for different market segments in Africa are not well understood. Further work needs to be done to identify why cost differentials exist in different market segments and countries. A sub-regional analysis for Africa – which brings together all stakeholders, from government, business, communities, project developers, financing and development partners – could help identify the reasons for cost differentials, map out strategies to reduce them, and identify roles and responsibilities.

More work needs to be done to understand why today's cost differentials in Africa exist, how new markets can shift rapidly to efficient installed cost levels, and how best to share these practical experiences to accelerate the deployment of solar PV in Africa.

It could be useful to explore co-ordination at a sub-regional level, where countries could discuss together with solar PV project developers, SHS businesses, policy makers and regulators how to exchange experiences of what has contributed to low-cost projects. This should look at present cost structure components (*e.g.*, module, inverters, other electrical, other hardware, permitting, installation, customer acquisition, etc.) and how these are affected by national circumstances (as opposed to outlining current cost levels). Sharing these experiences will help other countries to apply these lessons to their unique national and institutional circumstances.

A detailed assessment of the barriers and opportunities to replicating efficient cost structures in new markets will be needed to inform this approach. This will require an in-depth engagement on the ground with stakeholders (*e.g.*, project developers/business, policy makers, regulators, etc.) to identify these barriers and opportunities, as well as their applicability in different national circumstances. Regional dialogue (*e.g.*, through joint projects/workshops) can complement this analysis by helping to share different perspectives and identify the specific roles of each stakeholder in contributing to the successful implementation of cost reduction pathways.

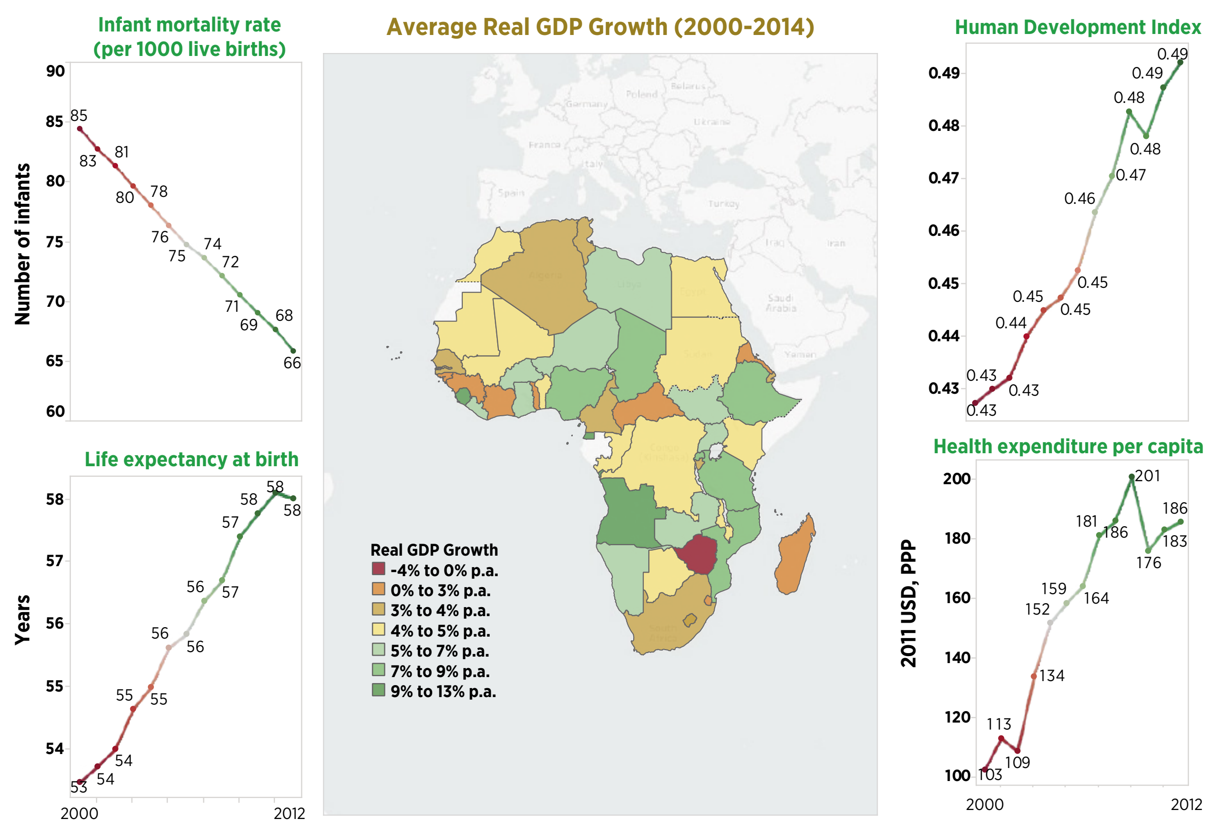
For SHS, issues of economies of scale and profit margins are paramount in arriving at efficient cost structures. African regions could consider the bundling of SHS deployment programmes (whether implemented by regulatory bodies, industry or social businesses) in order to achieve purchasing power benefits, and make financing more attractive and less costly. They also should aim for a measure of standardisation for products to help with training, installation and maintenance costs, and quality. Co-ordination could take the form of joint tendering, or be more hands-off, as in agreeing on standardised processes and specifications for national programmes.

1 INTRODUCTION

Renewable energy technologies can help countries meet their policy goals for secure, reliable and affordable energy; electricity access for all; reduced price volatility; and the promotion of social and economic development. Recent and expected cost reductions in renewable power generation technologies clearly show that renewables are now an increasingly cost-effective solution to achieve these goals. This is particularly important given the agreement in Paris in 2015 at COP21, as it gives confidence that the costs of the transition to a sustainable energy future can be managed and are declining. The virtuous cycle of policy support for renewable power generation technologies leading to accelerated deployment, technology improvements and cost reductions already has had a profound effect on the power generation sector. It also is setting the basis for what one day could be the complete transformation of the energy sector by renewable energy technologies.

For Africa, these developments in renewable power generation technologies could be a boon. Although African countries have made remarkable economic and social advances in recent years – economic growth has been rapid, while education provision, health care and other vital development indicators have improved (Figure 1) – many

Figure 1: Average real GDP growth and sustainable development indicators for Africa, 2000-2012/2014



Source: World Bank, 2015a

challenges remain. Economic growth is not evenly distributed, basic services and institutions often are still weak, more than 600 million Africans do not have access to electricity, and the provision of electricity services is erratic.

At the heart of many of the challenges facing African nations in the coming decades is the energy sector. Energy supply has not grown sufficiently to meet burgeoning demand. As many as 30 African countries have regular, sometimes chronic electricity shortages, leading to outages and the need for expensive back-up power generation facilities for those end-users that can afford the high costs of distributed diesel-fired generators. At the same time, 600 million people lack any access to electricity, and 700 million people rely on traditional biomass for their energy needs (World Bank, 2015a).With continued rapid population growth projected for Africa, expanding energy supplies and electricity access rapidly enough to meet the continent's needs will be a real challenge. Yet without adequate, clean and sustainable energy supplies, Africa will not be able to reach its full potential and to lift out of poverty the hundreds of millions of its citizens that still struggle.

Fortunately, Africa is rich in renewable resources. It has excellent hydropower resources yet has exploited only 8% of its technical hydropower potential (IRENA, 2015a). The northern, eastern and southern regions of Africa have excellent wind resources, while geothermal resources exist in East Africa where the Great Rift Valley crosses the region. Africa also has significant bioenergy resources, and traditional biomass use dominates the continent's energy supply, highlighting both its rich renewable resources and the poverty that contributes to the ongoing widespread use of open cook stoves, with their associated social, economic and health costs.

Renewable energy technologies can be part of the solution to many of these energy, economic and social challenges in Africa and around the world. Renewable energy can meet policy goals for secure, reliable and affordable energy, electricity access for all, reduced price volatility and the promotion of social and economic development. What is not widely appreciated is that with recent cost reductions, renewable power generation technologies can achieve these outcomes at a lower cost than alternatives. This represents a huge economic opportunity for Africa to embrace its domestic resources and to power its future with solar photovoltaics (PV) and other renewables.

The emerging potential of solar PV is perhaps the most exciting development on the continent from an energy perspective. Africa has excellent, widely distributed solar resources, yet the continent's solar PV and concentrating solar power (CSP) markets are in their infancy. Africa is home to only 2.1 gigawatts (GW) of the world's total installed capacity of solar PV, which reached a record 222 GW at the end of 2015 (IRENA, 2016b).Given the approximately 80% decline in solar PV module prices since the end of 2009 and the excellent quality of the solar resource throughout Africa, there is huge untapped economic potential for this highly modular and rapidly scaled technology.

Yet barriers to this pathway remain. Such a transformation will not happen without significant policy changes, improved institutional capability, new financing flows and a general improvement in the business sector. Cost-competiveness, however, is increasingly not a significant barrier today. The recent cost reductions for renewable power generation technologies, especially solar PV, as well as technology improvements when combined with the excellent renewable resources in Africa, has unlocked the exciting prospect that Africa's economic future could leapfrog the fossil fuel era, and it could be the first continent to see its development driven almost exclusively by renewable electricity.

Purpose and objectives

To enable a transition to a truly sustainable energy sector and to meet Africa's economic, social and environmental goals, the deployment of renewable energy technologies, especially power generation technologies, needs to be accelerated. However, there remains a lack of up-to-date data on the actual project costs of solar PV in Africa. Given the rapid decline in PV module prices and in installed costs in the last six years, this is a serious impediment to efficient policy making.

The risk is that without up-to-date data on real project costs, many assessments of the potential for solar PV in Africa are based on old, out-of-date data or, at the other extreme, on too optimistic assumptions that have been extrapolated from experience outside of the continent, or that are based on "expert judgement". As this report shows, this can result in misleading cost estimates for solar PV, since solar PV in Africa has quite a different cost structure[8] than in other regions. This report addresses this lack of information on the actual costs of solar PV projects and programmes in Africa, providing policy makers, decision makers and donors with real project data that can be used to assess the potential contribution of solar PV to meet economic, social and environmental development goals in Africa – thereby accelerating the deployment of solar home systems (SHS), mini-grids and utility-scale solar PV projects.

The aims of this report are to:

» Provide up-to-date, verified data on the range of costs and performance of solar PV in Africa for SHS, mini-grids (hybrid or 100% PV) and utility-scale projects.

» Provide an analysis of the current cost structure of solar PV systems in Africa and identify best practice cost levels and structures in different market segments.

» Ensure that decision makers in government, regulatory authorities, donors, financing organisations and the energy industry have the latest data to inform their decisions, policy making and regulatory setting.

» Provide powerful messages about the continued declining costs of solar PV technologies and their increasing competitiveness as an option for grid supply and as a means of accelerating electrification in Africa.

» Identify recommendations for the systematic collection of solar PV cost data in Africa in order to support decision makers and future work to unlock cost reduction potentials for solar PV in Africa.

In the past, deployment of renewables was hampered by a number of barriers, including their high upfront costs. Today's renewable power generation technologies are increasingly cost-competitive and are now the most economic option for any electricity system reliant on oil products (*e.g.*, some countries and off-grid electrification). In locations with good resources, they are the best option for centralised grid supply and extension. Yet, the debate around the potential role of renewable energy in meeting economic, social and environmental goals often continues to suffer from an outdated perception that renewable energy is not competitive. For solar PV in Africa, this report is designed to provide clarity on existing and upcoming project costs of solar PV on the continent, thereby ensuring that the analysis of solar PV is based on its true economic and technical merits, rather than on outdated or misleading information.

METHODOLOGY AND DATA CHALLENGES

Today, solar PV cost data in Africa are not systematically collected or made available to policy makers, resulting in difficulties in setting realistic policy support levels that are efficient and effective. The availability of better actual cost data, rather than assumptions, is one of the key aims of this report. The report presents the data that IRENA was able to collect for solar PV costs in Africa. The data for utility-scale projects from the IRENA Renewable Cost Database[9] were the starting point for the creation of a wider dataset that encompasses the SHS and mini-grid market segments as well.

8 The term "cost structures" in this report refers to the breakdown of total installed costs into their constituent components (*e.g.*, module, inverter, other hardware, installation, system design, battery, etc.).

9 The IRENA Renewable Cost Database contains the project-level details on the installed costs, capacity factors and levelised cost of electricity (LCOE) of 15 000 utility-scale renewable power generation projects around the world. It also includes data for around three-quarters of a million small-scale solar PV systems in North America and Europe, supplemented by secondary sources, where data gaps exist.

There are a number of important points to remember when interpreting the data presented in this report:

» All cost data in the report refer to the year in which the project is commissioned.

» All data are in real 2015 USD (that is, corrected for inflation).

» When average data are presented, they are weighted averages based on capacity.

» Cost data in this report exclude any financial support by governments (national or subnational) to support the deployment of renewables or to correct the non-priced externalities of fossil fuels.

» The levelised cost of electricity (LCOE) of solar technologies is strongly influenced by resource quality; higher LCOEs do not necessarily mean inefficient capital cost structures.

» Different cost metrics yield different insights, but in isolation they do not necessarily provide sufficient information to assess whether or not costs in different markets are at "efficient" cost levels.

The analysis here is designed to inform policy makers and decision makers about the trends in the relative costs and competiveness of solar PV. It therefore excludes the impact of government incentives or financial support for renewables. The analysis also excludes any system balancing costs or benefits associated with variable renewables, and any system-wide cost savings from the merit order effect. Furthermore, the analysis does not take into account any carbon dioxide (CO_2) pricing or the benefits of renewables in reducing other externalities, such as reduced local air pollution or contamination of the natural environment. Similarly, the benefits of renewables being insulated from volatile fossil fuel prices have not been quantified. These issues are important and will influence actors' decisions when assessing solar PV in different market contexts, but they are covered by other programmes of work at IRENA.

The process of collecting data for real-world solar PV project costs in Africa is challenging due to the small scale and fragmented nature of the market for solar PV on the continent, as well as confidentiality issues. IRENA's dataset is the largest and most comprehensive dataset available to the best of our knowledge. However, in some cases the data quality and coverage are variable. This makes data analysis time-consuming and can limit the range of analysis that can be undertaken.

IRENA has collected data for all of Africa from a wide range of stakeholders, as well as utilising existing data within the IRENA Renewable Cost Database for utility-scale projects that are operating, under construction or planned. Given the very thin market for solar PV in Africa, a reliance on older data (pre-2012) and proposed projects not yet commissioned is an issue that cannot be avoided. This needs to be borne in mind when drawing conclusions where data for the period 2009 to 2012 predominate, because although the cost structure may still be applicable, the overall level of costs for that period will be higher than today's reality given the rapid cost declines for solar PV in recent years.

Data were collected from as wide a range of sources as possible, including from GIZ country offices, IRENA focal points, Ministries of Energy, autonomous government authorities, electricity utilities, project developers and small-scale solar PV installers, energy-related economic communities, alliances and business associations, international development organisations,

Table 1: Countries for which solar PV cost data are available

East Africa	Kenya, United Republic of Tanzania, Uganda, Ethiopia
West Africa	Ghana, Senegal, Guinea Bissau, Burkina-Faso, Nigeria, Cabo Verde, Mali, Sierra Leone
Central Africa	Congo, Cameroon
North Africa	Tunisia, Egypt, Morocco
Southern Africa	South Africa, Zambia, Mozambique, Zimbabwe

Table 2: Cost breakdown of solar PV mini-grid and utility-scale systems

Module costs	Module make, size and cost
Balance of system (BoS) hardware cost	Inverter
	Racking
	Wiring and cables
	Monitoring system
	Battery
	Other hardware (transformer, protection devices, etc.)
	Duty and transportation cost
BoS soft (non-hardware) costs	Project development/ feasibility study cost
	Customer acquisition (sales and marketing costs)
	System design and procurement
	Subsidies (applications, fees, etc.)
	Permitting (application for permitting with utility provider and other authorities)
	Financing and contract (legal) fees
	Installation cost/ civil works
	Interconnection
	Performance and warranty
	Commissioning cost
	Training and capacity building

development banks and private companies. The total dataset covers around 400 projects (*e.g.*, at a utility-scale or mini-grids), programmes (*e.g.*, for rural electrification) or company-level data (*e.g.*, for SHS or aggregated data for several mini-grid projects). These real-world cost data cover 21 African countries (Table 1).

This report focuses on the current cost structure and overall installed costs of solar PV in Africa, although in some cases the competiveness of solar PV also is indicated. In addition to collecting data on total installed costs and technical parameters of the solar PV system (*e.g.*, size, level of battery storage, etc.), detailed data on cost breakdown were requested (Table 2). The data quality varied by respondent, and some responses could not be used because obvious errors or discrepancies meant that the data were not robust for the analysis proposed, even after seeking clarification from respondents.

In many respects, solar home systems more closely resemble consumer electronics products than electricity generation technologies. To allow for this, a simplified cost data breakdown was requested for these technologies, given that they typically are being sold by companies that are not manufacturers and that do not have access to the detailed cost breakdown. Costs for SHS therefore were divided into the following components:

- solar panel
- battery
- charge controller
- lamp and mobile charger
- soft costs, including transportation costs, mark-up and "all other" costs.

The size of the solar PV system, its configuration, and the amount and type of storage all have a material impact on total installed cost levels and their breakdown.[10] In trying to identify the drivers behind cost differences among projects, it therefore is very important to analyse solar PV systems in categories that are relatively homogeneous.

Solar PV system classification

For this project, IRENA has built on work conducted in 2014 (IRENA, 2015b) in providing a standard technical classification for on- and off-grid solar

10 It is important to note that for SHS in particular, costs do not usually equate to price levels. The relation between prices and costs can vary significantly, depending on the market, profit margins, taxation impacts, etc.

PV systems, and added the necessary market segment data as well as size in order to capture scale effects on installed costs (Table 3). As with any categorisation system, this is a compromise in terms of providing sufficient granularity to identify relevant cost differentials, while at the same time providing a sufficiently small number of categories to provide meaningful and easily understood analytical results. It is worth noting that this report often groups projects in a manner that provides for a robust analysis of their relative costs, sometimes at the expense of strictly adhering to the categorisation shown in Table 3.

The first major distinction to be drawn is between grid-connected systems and those operating off-grid. There are three market segments: utility-scale systems, commercial/institutional applications (*e.g.*, at businesses, educational facilities, hospitals, etc.) and residential systems, all of which can be on- or off-grid. The next useful distinction is between the means or scale of electricity distribution, whether it be stand-alone/building-level only (*e.g.*, SHS) mini-grids (*e.g.*, at a hospital, industrial facility or village) and the large-scale grid (always on-grid). From a cost perspective, this report also categorises systems by whether they include battery storage or not, as systems with batteries have significantly higher costs, as well as different cost structures, than systems without electricity storage.

The majority of solar PV capacity currently installed in Africa is in the form of utility-scale grid-connected projects, particularly in South Africa and the countries of North Africa. However, in terms of number of systems installed, SHS dominate, despite data not being available for identifying the exact numbers.

The analysis in this report excludes pico PV systems, such as solar lanterns, due to the difficulties of creating a comprehensive cost breakdown of such systems and also because they represent essentially a lighting solution, not an electricity supply solution, and fall outside the scope of this analysis. This is not to diminish this market segment's contribution

Table 3: Proposed categorisation of solar PV applications

	Stand-alone			Grids		
	DC		AC	AC/DC		AC
System	**Solar lighting kits or lanterns**	**DC SHS**	**AC SHS: single-facility AC systems**	**Nano-grid Pico-grid**	**Micro-grid Mini-grid**	**National/regional grid**
	Off-grid			Off-grid or on-grid		On-grid
Application	Lighting	Lighting and appliances	Lighting and appliances	Lighting and appliances, emergency power	All uses (including industrial)	All uses (including industrial)
Key component	Generation, storage, lighting, cell charger	Generation, storage, DC special appliances	Generation, storage, lighting, AC appliances, building wiring	Generation plus single-phase distribution	Generation plus three-phase distribution plus controller	Generation plus three-phase distribution plus transmission
Typical size	0-10 W	11 W to 5 kW	100 W to below 5 kW	5 kW to 1 MW		Residential (100 W to <5 kW) mini-grid (5 kW to <1 MW) and utility-scale (>1 MW)

Source: Adapted from IRENA, 2015b

Note: "Typical size" categories were created for the convenience of cost analysis.

to improving economic, social and educational development in Africa. This is vividly represented by the significant efforts to expand this sector in Africa.[11]

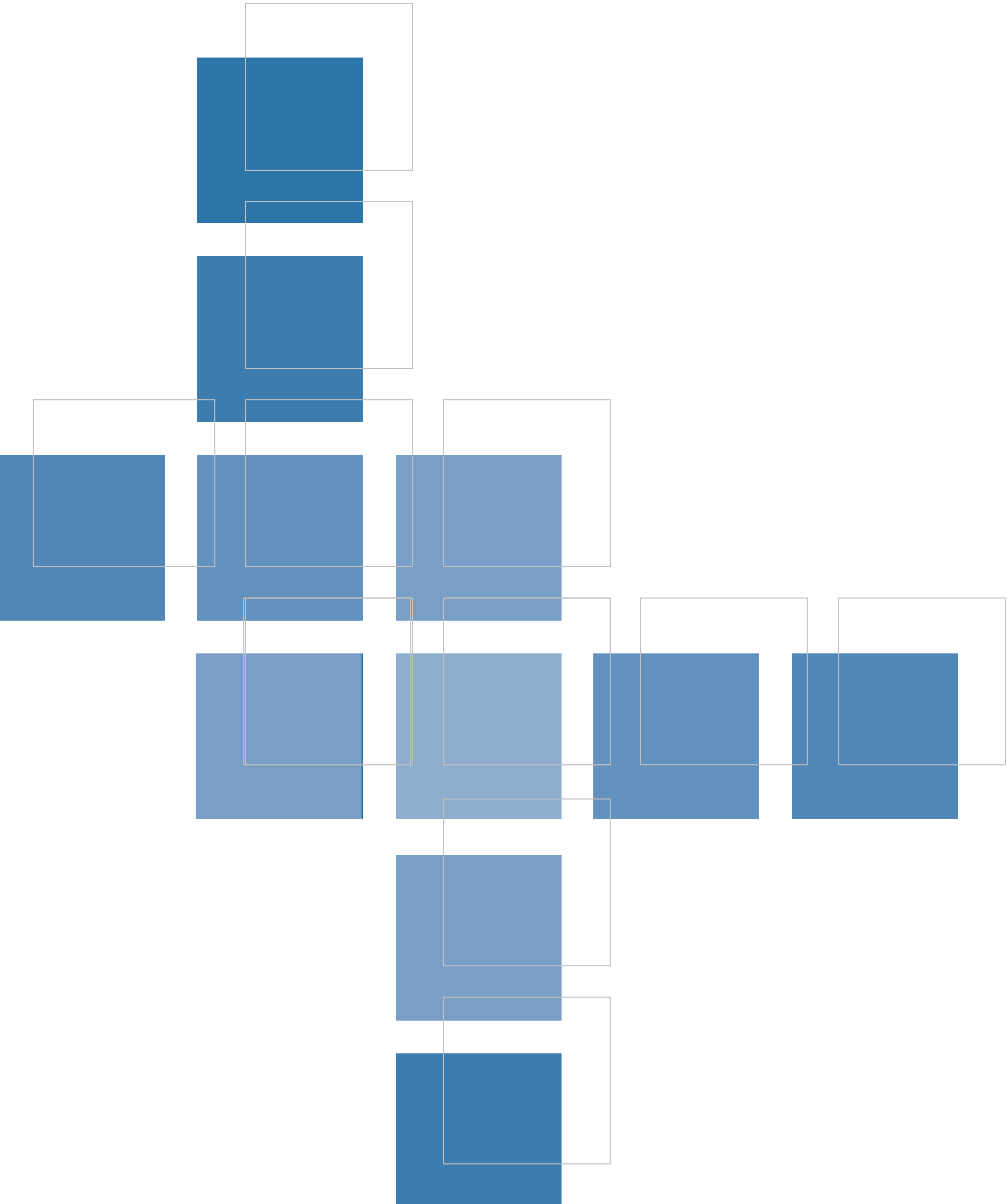
The solar PV market in most African countries is in its infancy, and the difficulty in finding partners to voluntarily share cost data is challenging. As a result, for SHS it is often difficult to identify whether the data available are representative cost data that allow a deep analysis of underlying cost structures. This was also true for utility-scale systems, where although comprehemsive total installed cost data were available, confidentiality concerns meant that no developer was prepared to share a detailed cost breakdown. As a result, the data quality is sometimes variable and limited the potential for detailed analysis that would allow an understanding of the efficiency of current cost structures and how they might evolve over time.[12]

Importantly, the difficulties in trying to gather data arose not only when contacting private companies, but also with financing agencies, development partners and government agencies. Very often the collection of cost data simply was either not carried out or no one individual entity had a full overview of the total cost of the project. This was somewhat surprising and concerning, considering that these projects benefited from the use of overseas development aid and finance, or other public funds.

Such challenges might be expected for smaller projects, but even large development or aid programmes typically did not collect cost data systematically for the products deployed within the overall financial envelope for the project. Under such circumstances it is difficult to see how a proper evaluation of a project or programme's technology costs can be undertaken, and it raises questions about missed opportunities to drive down costs over time. Although the goals of these programmes often go beyond just electricity access or extension, the data collection challenge still represents a significant weakness of many of the current programmes in Africa.

11 For example, see the Lighting Africa programme from the International Finance Corporation (IFC) and the World Bank that covers the analysis of the pico PV system market regularly with data on the distribution and quality of such systems, as well as other issues.

12 The data provided were often incomplete with regard to the cost categories identified. The breakdown of project costs therefore is not always consistent from project to project.



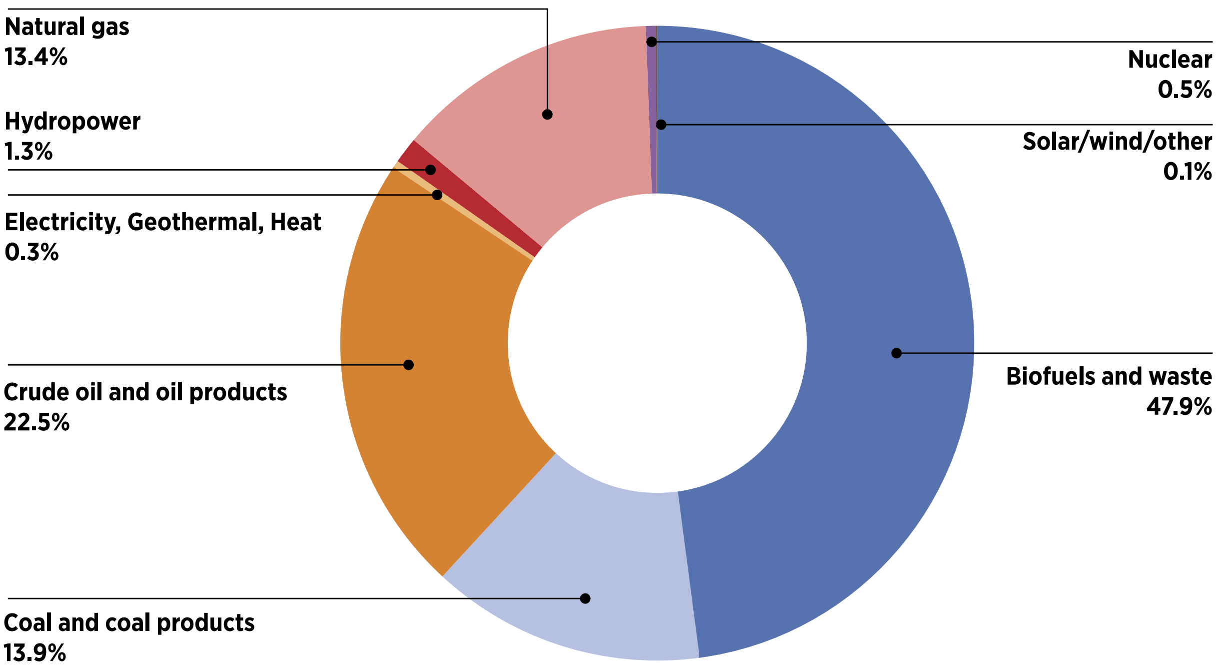
2 AFRICA'S ENERGY SYSTEM TODAY: STATUS, CHALLENGES AND OPPORTUNITIES

The total primary energy supply (TPES) in Africa has more than tripled since 1971 and has been growing at around 3% per year, one of the most rapid rates for any region (IRENA, 2015a). Despite this growth, Africa is still highly dependent on traditional biomass (Figure 2), and modern energy use on the continent remains low, with no other region of the world having such a high share of traditional biomass use in TPES. In some African countries there is very little modern energy service provision: for example, the share of bioenergy is more than 90% in Burundi, the Central African Republic and Rwanda (IRENA, 2013a).

In 2013, oil accounted for about 22% of Africa's TPES, but the continent exports more than 80% of the oil it produces. Hydropower, wind, solar and nuclear account for 2-3% of the TPES. TPES per capita on the continent is among the lowest in the world, at around 0.7 tonnes of energy equivalent (toe) per capita (0.6 toe/capita in sub-Saharan Africa) (IEA, 2014a). It is around one-sixth of the TPES per capita in OECD countries, at over 4 toe/capita. Excluding traditional biomass use would raise this ratio significantly.

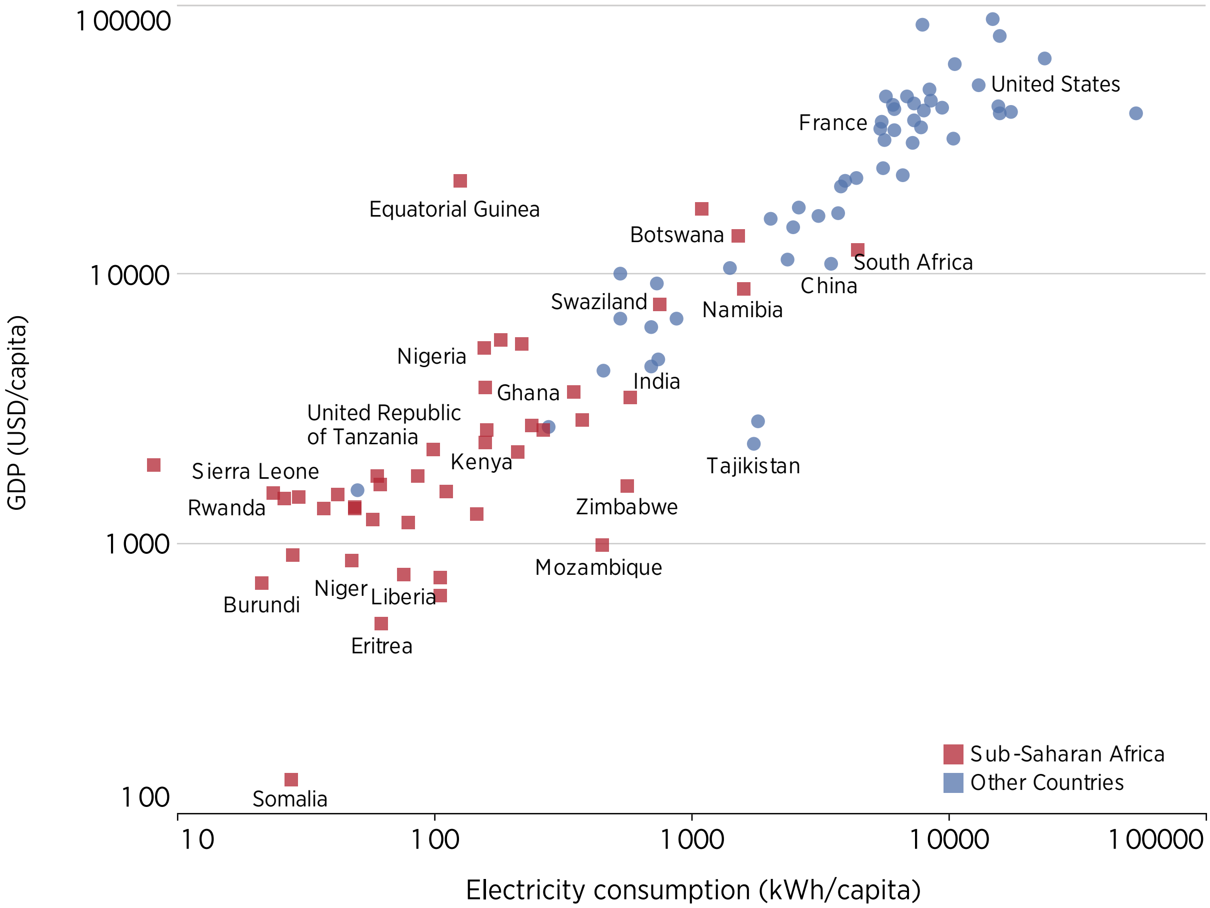
Access to adequate energy supplies and economic growth are interlinked. It therefore is no surprise to see that electricity consumption per capita in Africa is low (Figure 3). Yet even on this relative benchmark, some African countries perform poorly. Electricity consumption per capita is significantly lower in some sub-Saharan African countries even compared to other countries with

FIGURE 2: TOTAL PRIMARY ENERGY SUPPLY IN AFRICA



Source: IRENA, 2015a

Figure 3: Relationship between electricity consumption and GDP, 2012



Source: US CIA, 2016 and World Bank, 2015a

Note: A logarithmic scale was used on both axes of the figure.

similar levels of per capita gross domestic product (GDP) (*e.g.*, Tanzania compared to Tajikistan). Electricity production per capita in 2012 in Africa averaged 664 kilowatt-hours (kWh), compared to 9 170 kWh per capita in the OECD countries and the global average of 3 220 kWh per capita.

When compared to OECD countries, the difference is stark. For example, Nigeria's and Kenya's electricity consumption per capita are 147 kWh and 153 kWh, respectively, compared to 12 210 kWh in the United States and 6 869 kWh in France. Electricity consumption per capita in these two OECD countries is 45 to 83 times higher than in Nigeria and Kenya (Africa Progress Panel, 2015).

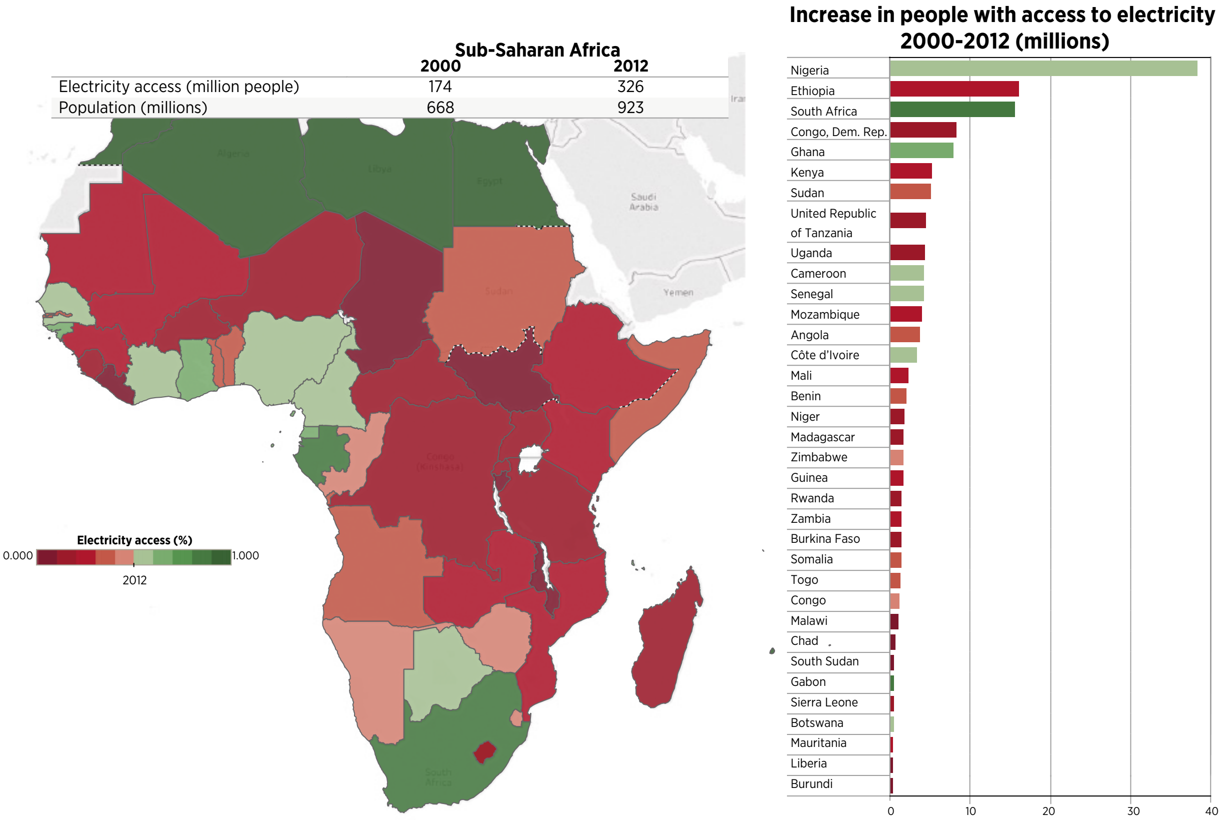
This reflects a range of factors, but two factors largely drive this dynamic:

» Low electricity access rates in sub-Saharan Africa, and

» Investment in electricity generating assets that has lagged behind underlying demand growth.

This has led to low rates of electricity consumption, even compared to income levels in some countries, and insufficient investment in generation capacity has had severe economic consequences. Addressing the deficiency in electricity generating capacity and, critically, output, given the significant unavailability of existing thermal and often hydropower plants, as well as improving electrification rates, would reap huge social and economic dividends. The energy sector bottlenecks and power shortages cost the region 2-4% of GDP annually, undermining sustainable economic growth, jobs and investment (Africa Progress Panel, 2015). The costs are not just economic, but also social. Africa's poorest people are paying among the world's highest prices for energy services: householders in a village in northern Nigeria spend around 60 to 80 times more

Figure 4: National electrification rates by country in Africa



Source: IEA, 2014a and World Bank, 2015b

for each unit of useful light than a resident of New York City or London.

Electricity access

The electrification rate (the percentage of the population with access to electricity) in sub-Saharan Africa is the lowest of any developing region. Electrification rates in sub-Saharan Africa rose from 22.7% in 1990 to 26.1% in 2000, and reached 35% in 2012 (World Bank, 2015a). Every country in sub-Saharan Africa has seen electrification rates rise between 2000 and 2012, except The Gambia, where the percentage rate was roughly constant (Figure 4). With population growth between 2000 and 2012, this has resulted in 150 million sub-Saharan Africans gaining access to electricity since the year 2000.

The situation is not aided by the high incidence of poverty in Africa and by the challenges that many Africans face in paying for modern energy services. Africans with irregular and extremely low incomes struggle to pay for modern energy services, and they end up paying relatively high prices for poor-quality energy services (*e.g.*, the use of candles or kerosene lanterns). However, in recent years a growing African middle class[13] and access to low-cost lighting imports have caused rapid shifts in the lighting share in some countries, as Africans shifted from kerosene to LED lights powered by batteries, solar lanterns or SHS kits.

Significantly improving the electrification picture is not just a challenge, but a huge investment opportunity that increasingly is being met by socially conscious entrepreneurs. Millions of energy-poor, disconnected Africans, who earn less than USD 2.50 a day, already constitute a USD 10 billion yearly energy market (Africa

13 This is a relative concept, as it covers the one-third of the population that spends USD 2 to USD 20 a day.

Progress Panel, 2015). Despite the small-scale nature of individual transactions and a range of other difficulties, the opportunities for providing clean, sustainable renewable power rapidly to Africa's rural communities via SHS and solar PV mini-grids represents an exciting development opportunity.

Energy service quality

Underpinning the relatively modest track record for electricity access and investment in supply is a lack of adequate infrastructure in Africa. This also is true for the electricity network. Around two-thirds of the countries in sub-Saharan Africa have transmission networks where 50% or more of the lines are at least 30 years old (EC JRC, 2014). Even in South Africa, 30% of transmission lines are at least 30 years old. The chronic lack of investment in infrastructure, leading to challenges with maintenance and aged infrastructure, all contribute to the very common blackouts of grid power supply in sub-Saharan Africa.

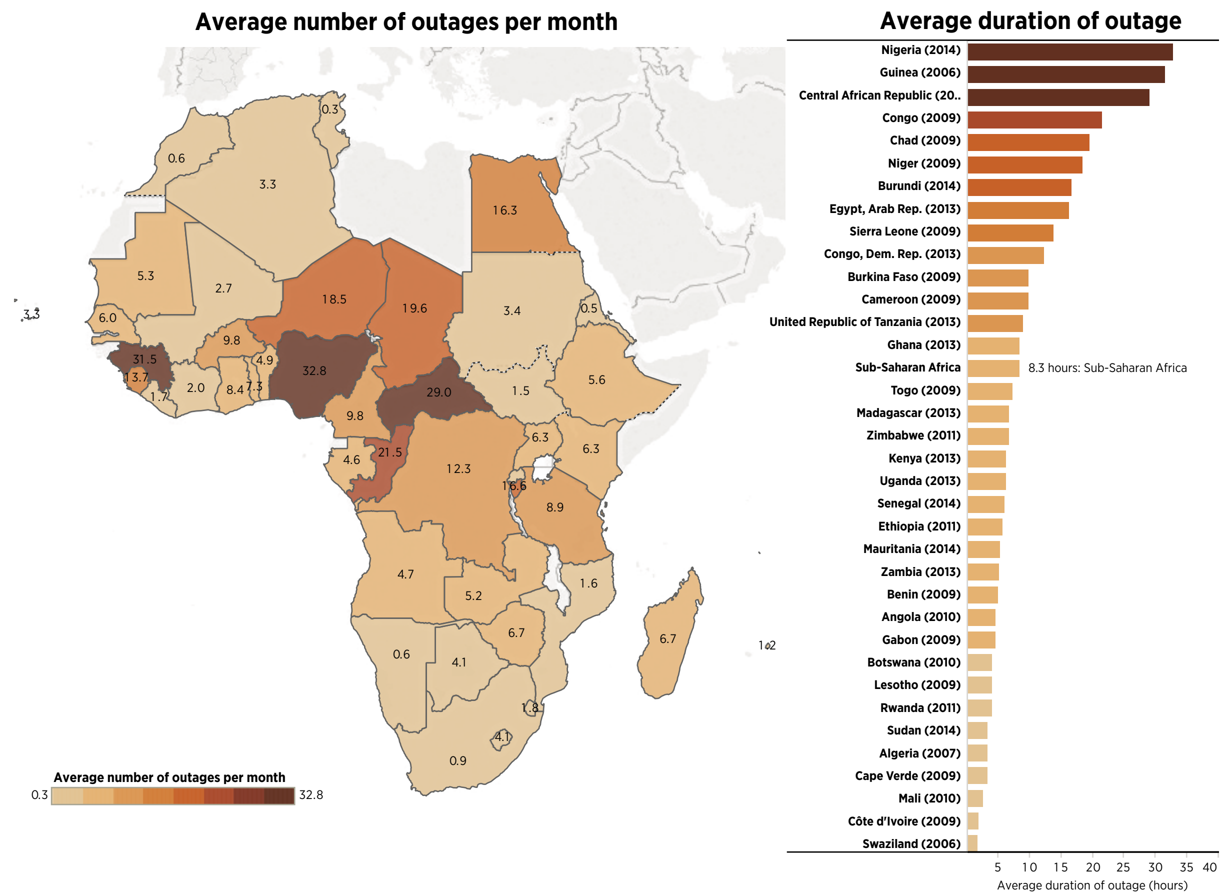
As a result, and due to inadequate supply capacity, even where modern energy services are available, quality can be lacking. Electricity supply in sub-Saharan Africa is often unreliable, with blackouts and brownouts the norm in many countries, and unmet demand means that economic growth is lower than it otherwise might be. The inability of power generation capability to grow to meet the underlying demand for electricity in Africa is creating one of the continent's greatest challenges. The costs are felt across the African economy and, in some countries, are crippling. African manufacturing enterprises experience on average 56 days per year of power outages. Companies lose 6% of sales revenues in the manufacturing sector, and the losses can go as high as 20% when back-up generation is not available and/or expensive (World Bank, 2015b).

The reasons for the crises in many African electricity systems are varied and differ by country. However, common causes are: drought (affecting hydropower capacity), poor maintenance (often related to poor utility revenues and profitability) that reduces plant availability, systems disrupted by conflict (it can take years or decades after a conflict ends for the electricity sector to recover), and high demand growth and structural issues in the electricity sector that have held back investment in supply, transmission and distribution (World Bank, 2008). Another challenge is the generally difficult business environment that exists in Africa.

Figure 5 highlights just how serious the underinvestment in power generation capacity is in sub-Saharan Africa. Eleven countries in Africa experience an average of 10 or more electrical outages per month, and five experience an average of 20 outages or more per month (World Bank, 2015c). The average duration of these outages in sub-Saharan Africa was 4.6 hours, with 17 countries having outage durations that exceed this average.

Yet the situation is not static, as the demand for electricity is expected to grow rapidly in Africa in coming decades. By 2100, Africa's population could quadruple, making it home to more than 4.4 billion people (UNDP, 2015). Most of the growth will occur in the sub-Saharan region. With growing economies and rising standards of living in Africa, in the next 15 years alone electricity demand is expected to grow more than three-fold (IRENA, 2015a). This continued rapid growth will require large investments just to ensure that electricity supply quality does not deteriorate and that electricity access levels do not decline due to population growth outstripping new connections.

Figure 5: Electrical outages per month and average duration in Africa

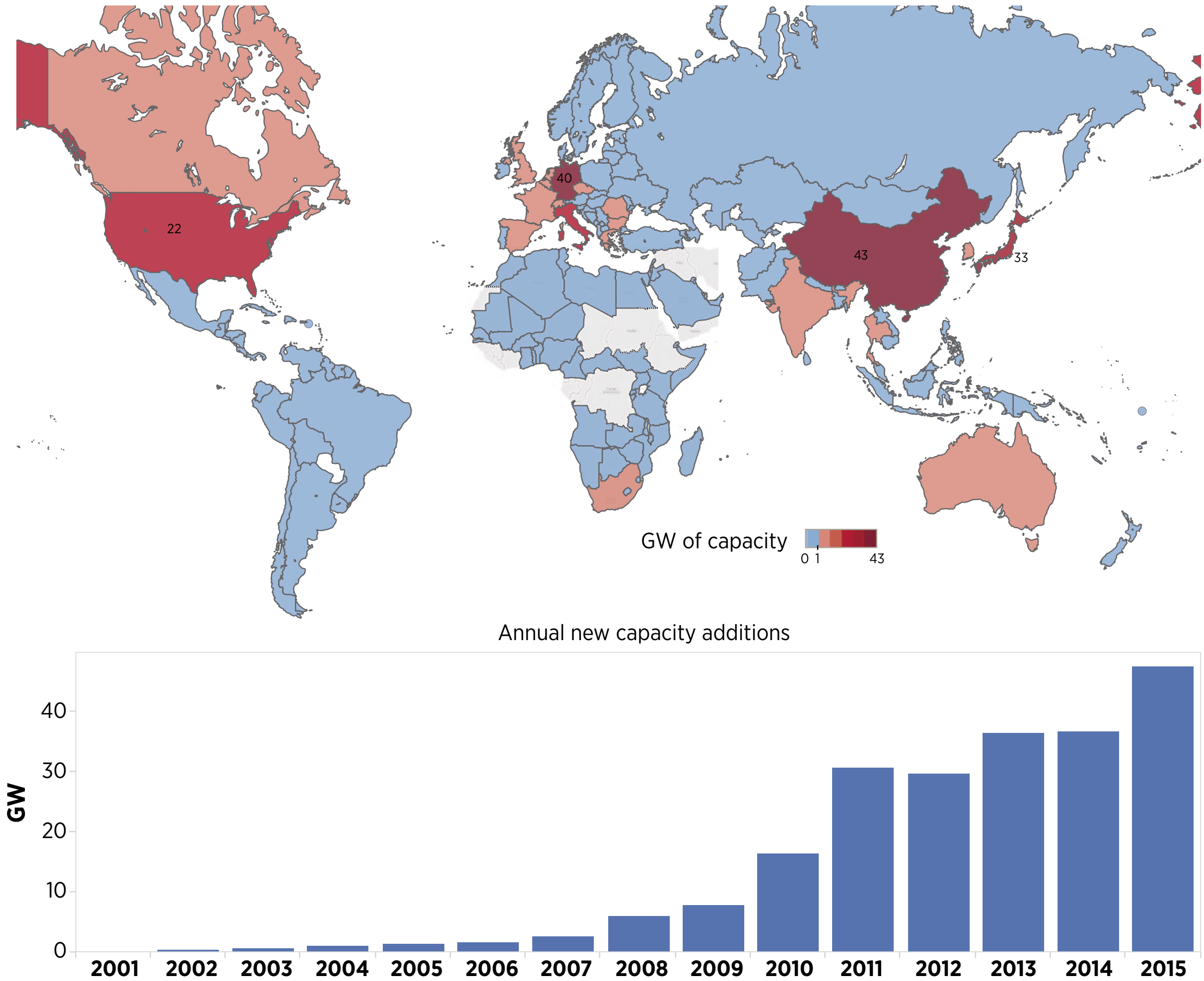


Source: World Bank, 2015a

3 THE GLOBAL AND AFRICAN SOLAR PV MARKETS

Cumulative global installed capacity of solar PV has risen from 0.8 GW in 2000 to 222 GW at the end of 2015. Annual new solar PV capacity additions reached a new record of 47 GW in 2015. The rapid growth of PV installation worldwide since 2000 has been remarkable. However, the market for solar PV is still focused on a narrow range of OECD countries. In 2015, the top five countries accounted for around 80% of total solar PV deployment. The growth in solar PV has largely missed the areas with good solar resources, although since 2011 China, India and South Africa have become major markets. More recent developments are even more exciting, as the market is starting to change fundamentally. The recent development of PV markets in Brazil, Chile, Dubai, India, Jordan, Mexico, Peru and South Africa has shown that solar PV can now compete on cost terms with fossil fuels, even in the absence of financial support.

Figure 6: Global cumulative installed solar PV capacity by country and annual new additions, 2000-2015



Source: IRENA, 2016a

Note: Countries in blue have less than 1 GW of cumulative installed capacity of solar PV.

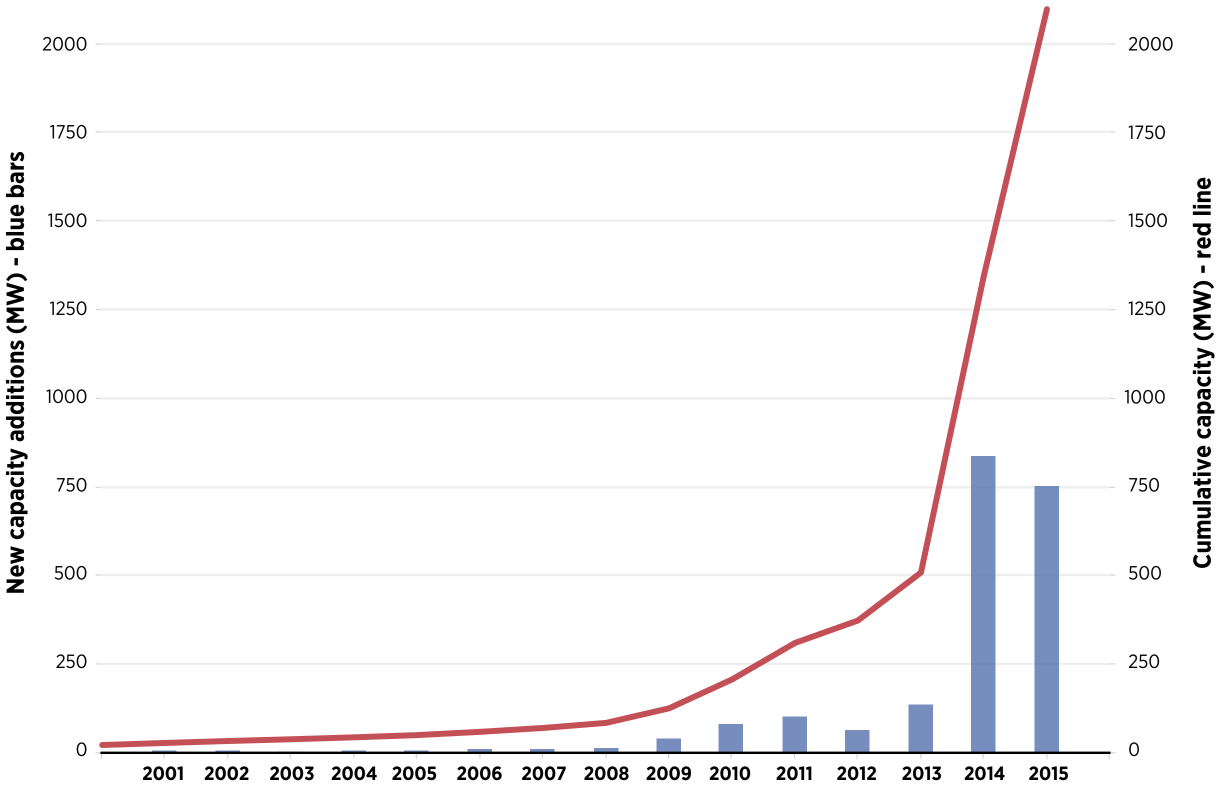
Solar PV in Africa

IRENA data and statistics show that Africa's total cumulative installed capacity of solar PV jumped from around 500 MW in 2013 to around 1330 MW in 2014 and 2 100 MW at the end of 2015 (Figure 7). Total installed solar PV capacity therefore more than quadrupled in two years. Total installed solar PV in Africa is dominated by South Africa, where an increased number of installations have been carried out in recent years under the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). South Africa now accounts for 65% (1 361 MW) of the continent's cumulative installed solar PV capacity, Algeria for 13% (274 MW), Réunion for 9% (180 MW) and Egypt for 1% (25 MW). Uganda, Namibia and Kenya also account for around 1% each, with between 20 MW and 24 MW each.

In 2015, South Africa and Algeria accounted for 710 MW (95%) of the 751 MW added that year. Aside from South Africa and Algeria, in 2014 and 2015 Mauritius, Rwanda, Réunion, Tunisia, Namibia and Egypt were the largest markets, but this typically represented the connection of just one or two utility-scale projects – the largest annual addition being the 16 MW added in Mauritius in 2014. However, Africa's potential far surpasses today's deployment and rates of new additions. In IRENA's REmap analysis of how to double the share of renewable energy in the world's energy system by 2030, Africa could see total installed capacity of solar PV increase to 70 GW or more.

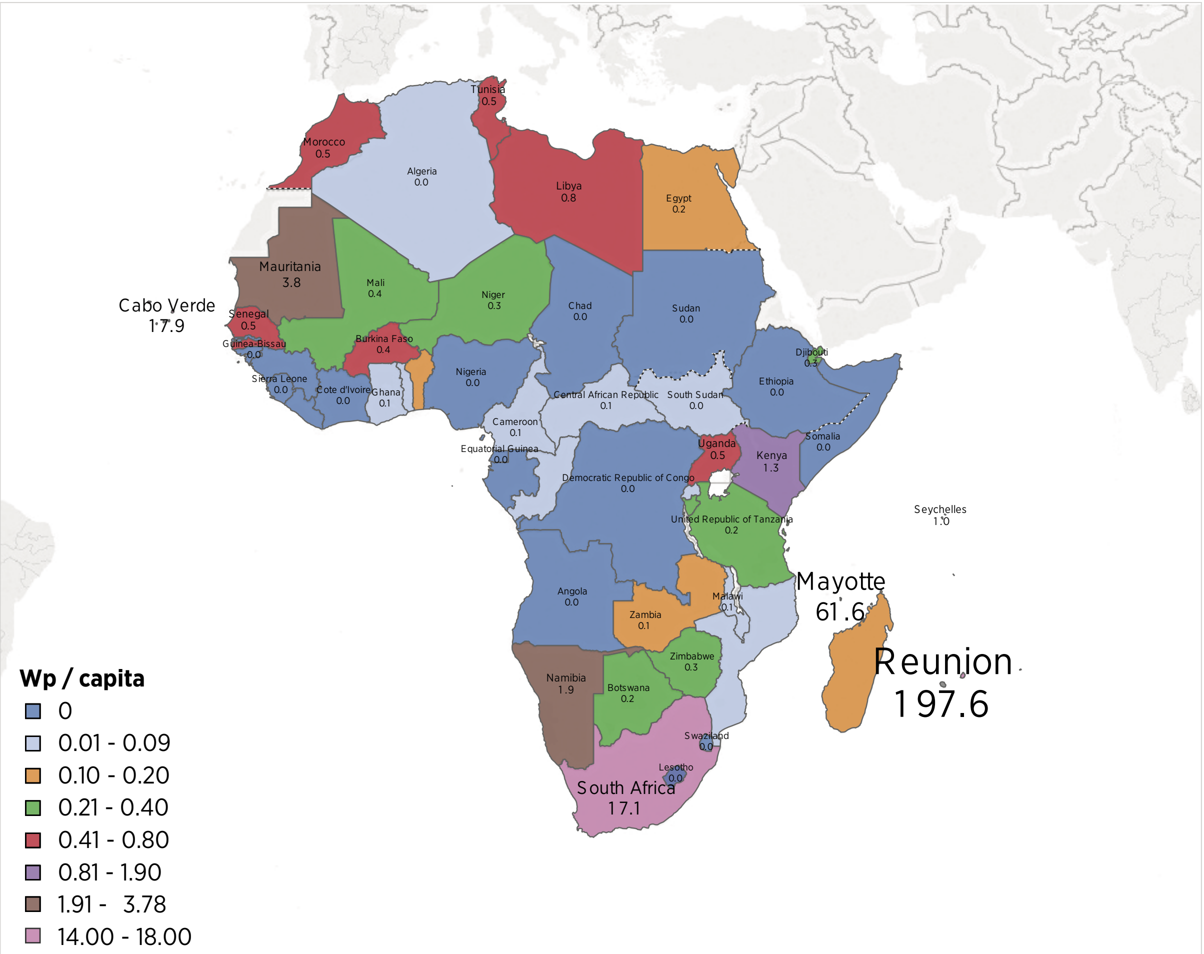
As Figure 8 demonstrates, the installed capacity in Africa in relation to the population is modest, despite the excellent solar resource in Africa. Figure 8 also highlights the problem of adequate data on solar PV use, as a range of countries do not report any solar PV capacity, and an estimate cannot be made robustly from secondary sources (*i.e.*, global trade data that track PV components)

Figure 7: Africa's total cumulative installed capacity of solar PV, 2000-2015



Source: IRENA, 2016a

Figure 8: Map of installed solar PV capacity in watts per capita, 2015



Source: IRENA, 2016a

despite the existence of distributors of solar PV systems in these countries.[14]

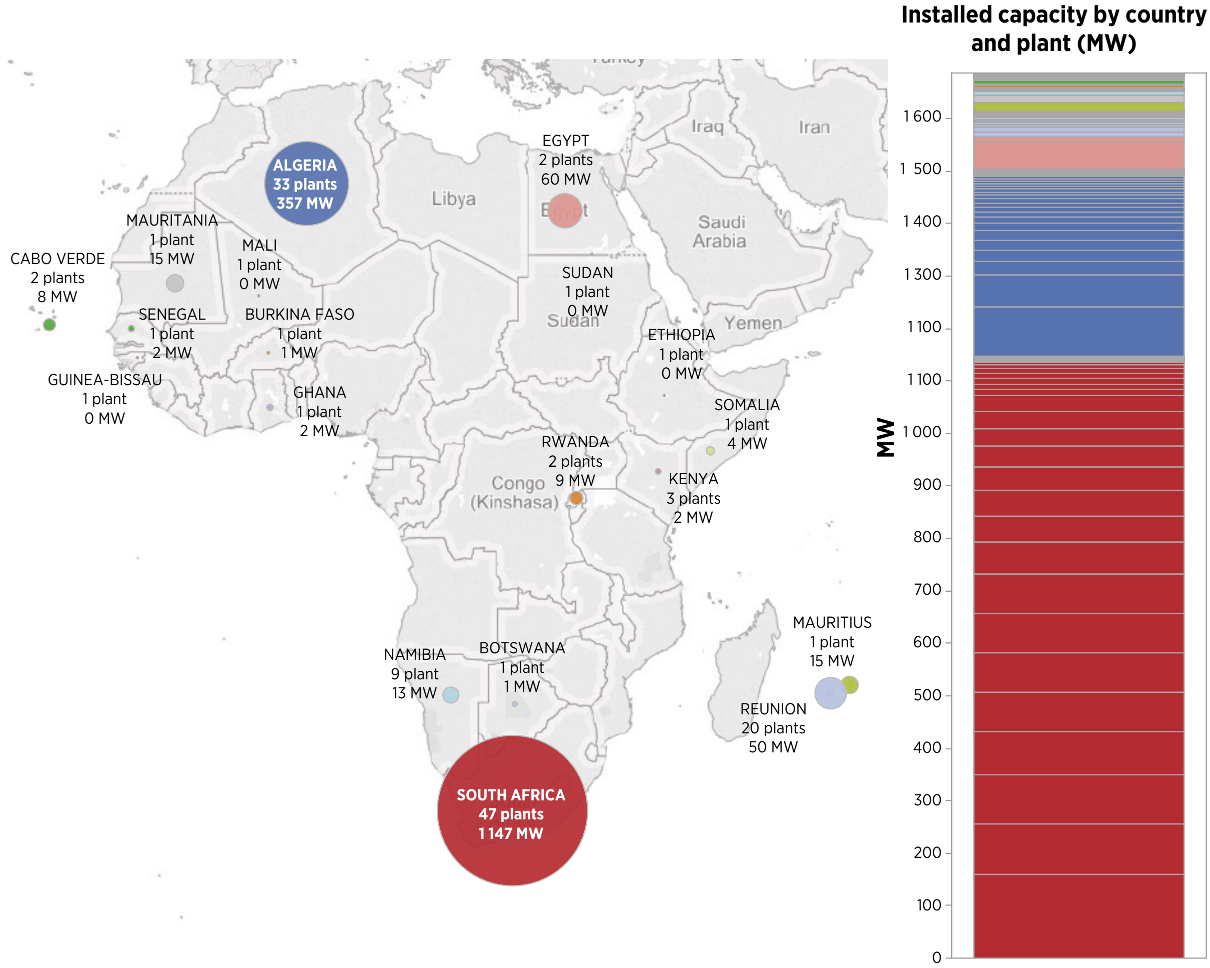
Figure 9 presents a map of solar PV projects of 100 kW or larger for which specific capacity data are available. The country with the highest installed capacity of PV plants in Africa is South Africa, with around 1 000 MW of installed capacity. This is followed by Algeria with around 300 MW. However, most countries in sub-Saharan Africa have no large-scale PV plants installed at all.

Reasonable data are available for large utility-scale solar PV projects in Africa, but data on the number and capacity of solar PV projects deployed in other market segments are woefully lacking. This is an important issue, because although the utility-scale grid-connected solar PV market is the largest market in Africa in terms of MW deployed, the off-grid market is the largest in terms of number of systems deployed (IRENA, 2015b). The off-grid market comprises SHS and mini-grid systems. Some mini-grid systems can be large and represent utility-scale MW-sized networks. The off-grid markets play a vital role in electrifying Africa, as mini-grids can be the most economical solution for remote areas, and the opportunity to deliver a commercially sustainable power supply through solar PV is very large (EUEI PDF and GIZ, 2014).

Current statistics on mini-grid systems and larger solar PV systems in Africa are unlikely to be comprehensive given the fractured nature of

14 In some cases, recent census surveys can at least help inform estimates of the importance of solar PV systems for lighting. Future research by IRENA, dependent on resources, will explore whether it is possible to model deployment trends from census data for Africa in order to arrive at country estimates.

Figure 9: Operating large solar PV plants in Africa (100 kW-plus system size), Q1 2016



Source: Platts and IRENA, 2016a

Note: The scale of PV plants was rounded to "0" for plant sizes under 500 kW, and to "1" for plant sizes above 500 kW and below 1 MW. Data may not be complete for each country..

the market and the high costs of data collection. Current estimates indicate that around 1.3 MW of these system types may be operating in Africa (Platts, 2015). Around half of this deployment is in just four countries: South Africa, Egypt, Kenya and Tanzania.

Small PV systems for single households can now provide basic electricity services at a cost similar to or even lower than existing energy expenditure, and hundreds of thousands of people have already purchased such systems (UNDP and GEF, 2004). Yet the off-grid SHS markets in Africa are still relatively small (Table 4). Bangladesh has significantly more SHS than Africa due to a very successful, long-running implementation programme, with around 4 million SHS installations in place as of April 2016.

Table 4: Status of off-grid solar home system markets in several African countries and Bangladesh

Country name	Year	Number of SHS	Population (million)
Bangladesh	2016 (April)	4 000 000	161
Kenya	2010	320 000	47
South Africa	Est.	150 000	55
Morocco	Est.	128 000	34
Zimbabwe	Est.	113 000	16
United Republic of Tanzania	Est.	65 000	51

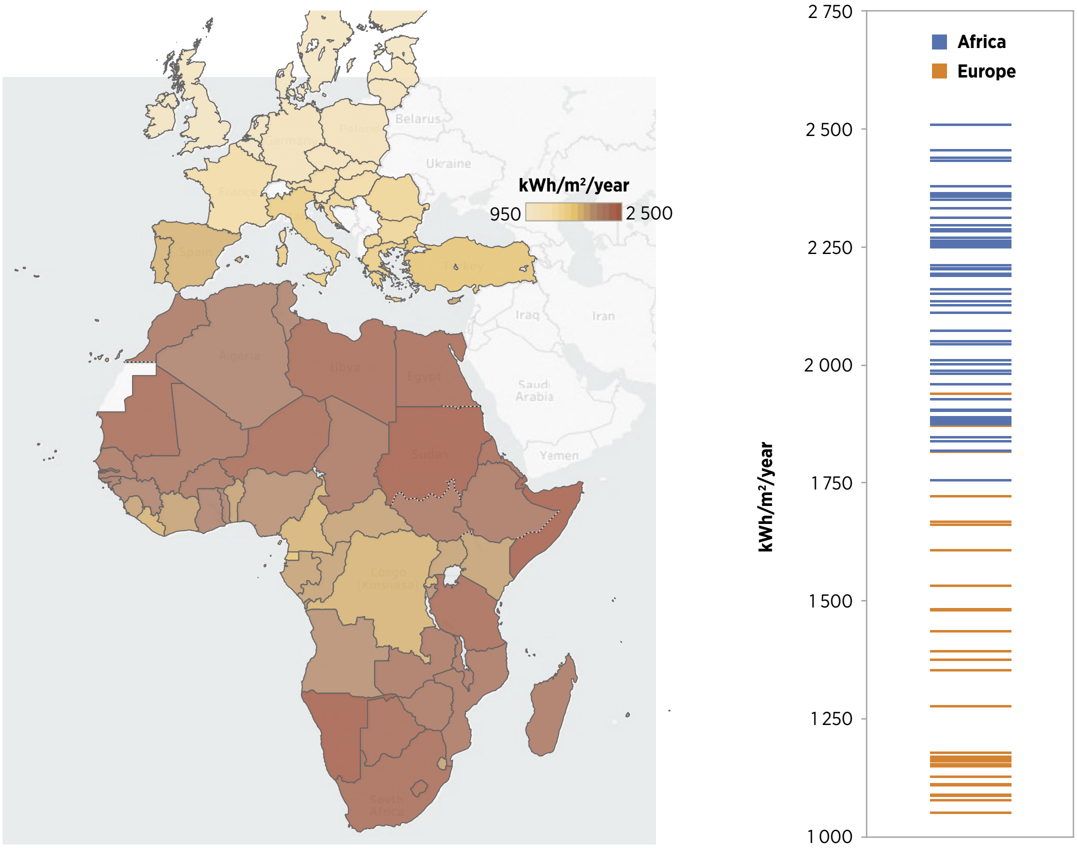
Source: IRENA, 2015b

BOX 1

Africa's solar resource

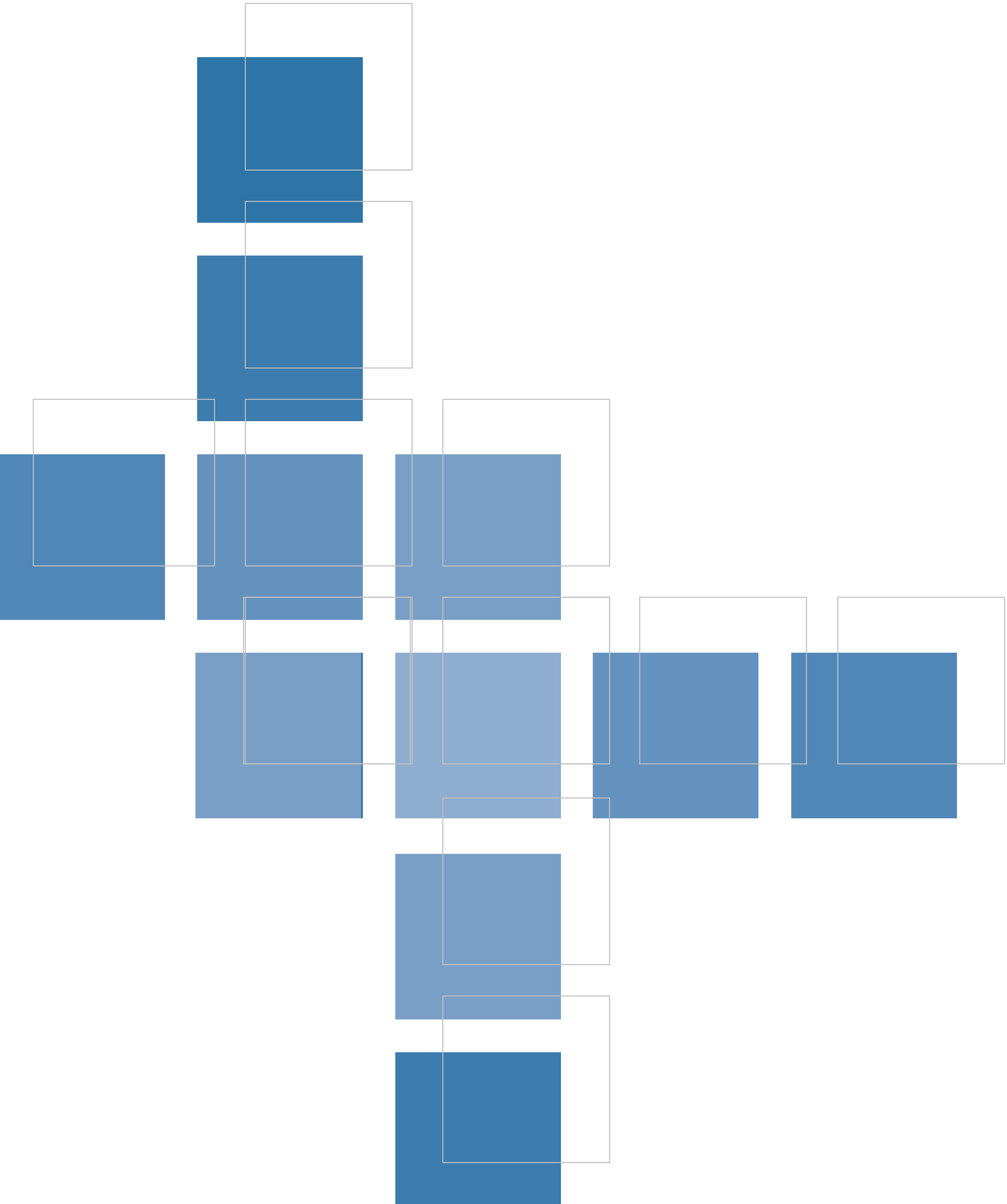
Africa's PV potential is very large, and few other areas on Earth have such consistently excellent solar irradiation resources. The average solar resource in Africa by country is significantly better than in most European countries. For instance, in Germany where 40 GW of installed solar capacity is in place, the average irradiation value is just over 1 150 kWh/m²/year if the slope is optimised, yet in the capitals of African countries it ranges between 1 750 and 2 500 kWh/m²/year. In total, 39 African countries have a solar resource that exceeds 2 000 kWh/m²/year. Namibia, with a solar resource of 2 512 kWh/m²/year, has the highest solar resource in Africa for its capital, but has cumulative installed capacity of just 21 MW. With these high and widely distributed solar resources, the economics of solar PV are given a boost due to the excellent capacity factors of solar PV systems.

FIGURE 10: SOLAR RESOURCE ON AN OPTIMALLY SLOPED SURFACE IN EUROPE AND AFRICA



Source: EC JRC, 2015

Note: Each horizontal line represents and individual country value for the solar resource.

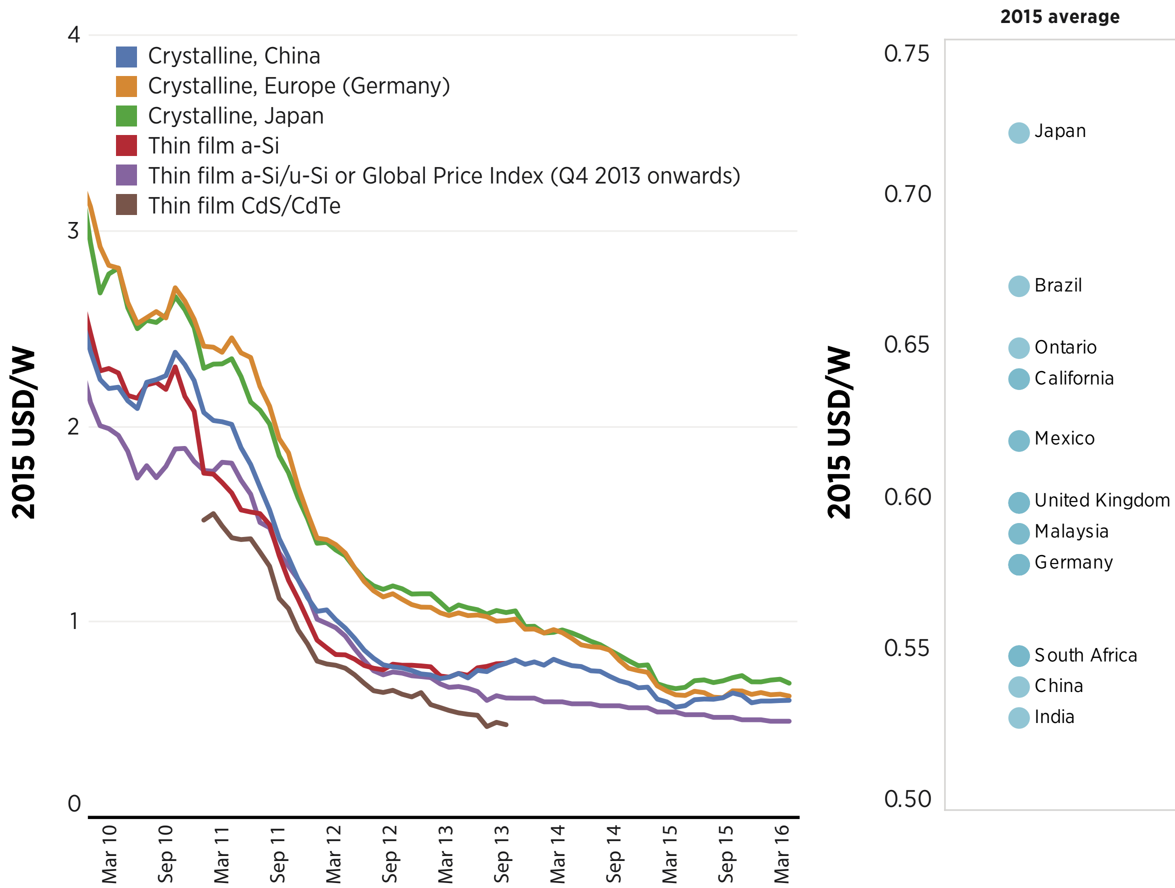


4 GLOBAL SOLAR PV COST TRENDS

The accelerated deployment of renewable power generation technologies offers the opportunity for Africa to leapfrog the fossil fuel-intensive development pathway that characterised industrialisation and economic growth in OECD countries (IRENA, 2015a). Renewable power generation technologies represent a mature, clean, sustainable and increasingly competitive solution to increase electricity production, expand electricity access and decrease dependency on fossil fuels in Africa (IRENA, 2015c). Many African countries already rely heavily on hydropower for electricity generation, and additional hydropower could be deployed, but lead times are long and it can take 10 years or more to go from project conception to generation. With technology improvements and cost reductions, solar and wind power technologies have emerged as viable alternatives to fossil fuels.

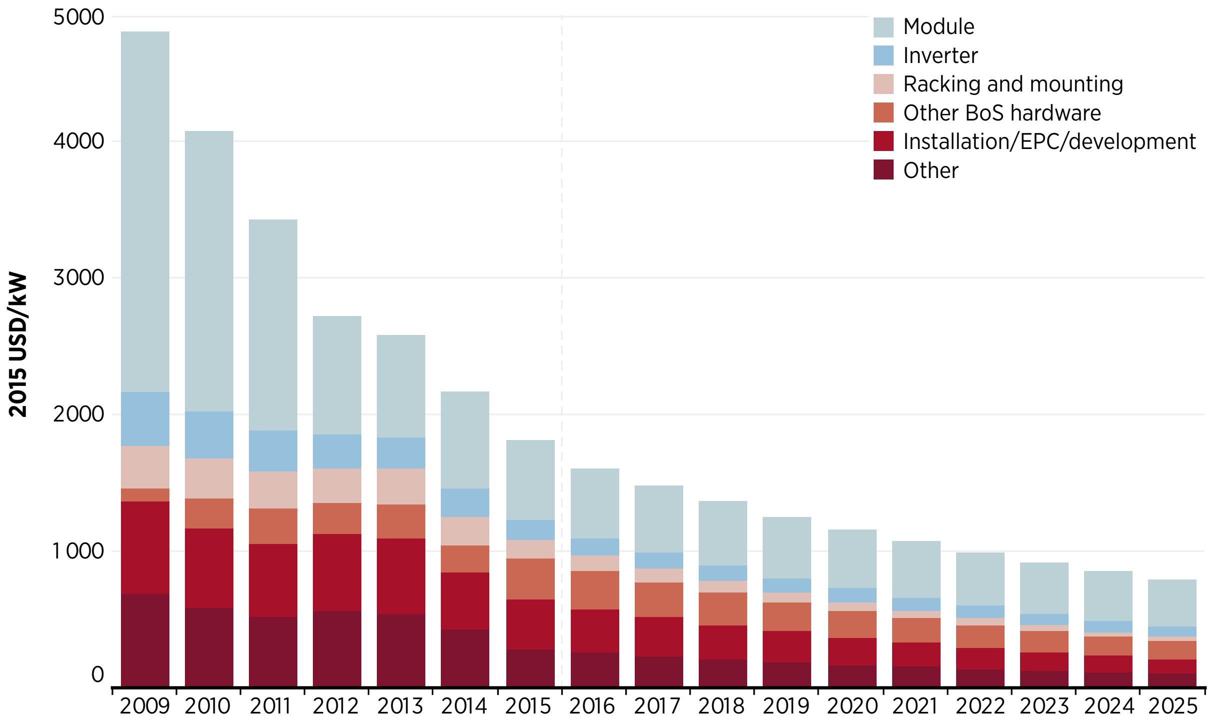
Solar PV module prices declined by around 80% between 2009 and 2015 (*Figure 11*). In 2011, price declines accelerated as oversupply created a buyer's market. The price declines then slowed between 2013 and 2015 as manufacturer margins reached more sustainable levels and trade disputes set price floors in some markets. During Q1 2015, solar PV module prices continued declining by about 15% for crystalline modules and by a slower 4% for thin-film modules. Module prices stabilised during Q3 and Q4 2015, with crystalline modules increasing slightly. Thin-film module prices

FIGURE 11: AVERAGE QUARTERLY SOLAR PV MODULE PRICES BY TECHNOLOGY AND MANUFACTURING COUNTRY SOLD IN EUROPE, 2010-2016



Source: pvXchange, 2016; GlobalData, 2016; and Photon Consulting, 2016

Figure 12: Global weighted average utility-scale installed solar PV system costs and breakdown, 2009-2025



Source: IRENA analysis and Photon Consulting, 2016

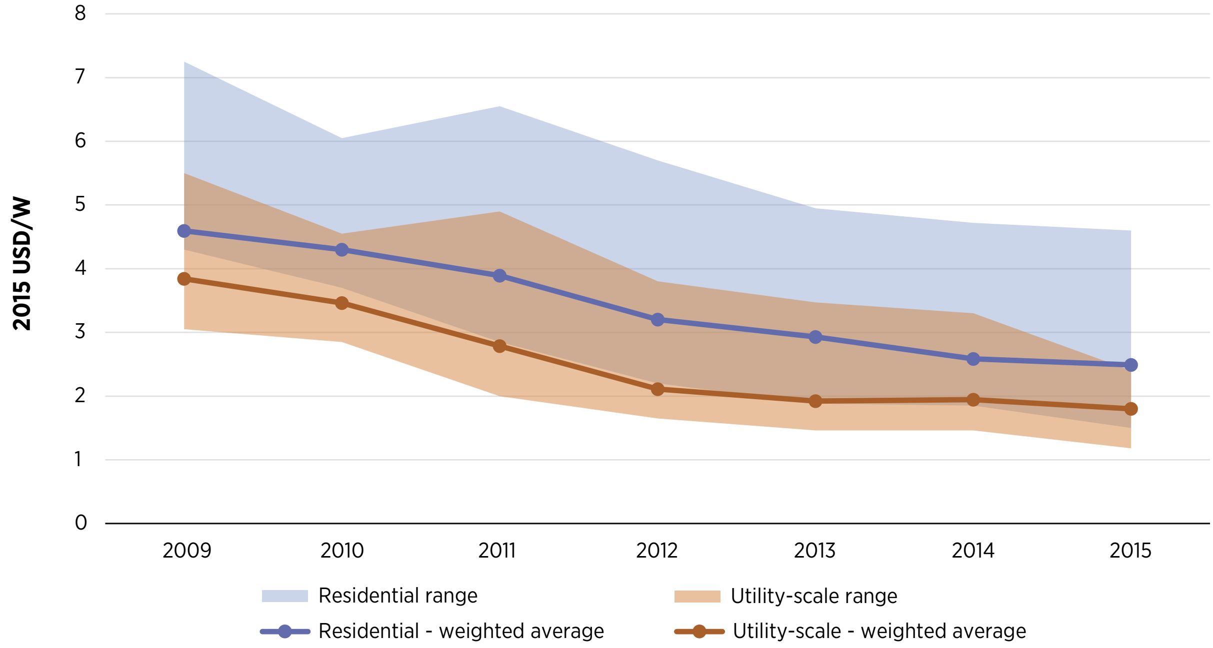
continued their downward trend and decreased 3% during Q2, Q3 and Q4 2015. During early 2016, thin-film prices have stayed around USD 0.5/W. During 2015, weighted average country level module prices ranged from around USD 0.52 to USD 0.72/W.

Falling solar PV module and BoS costs have seen the global weighted average total installed costs of utility-scale solar PV plants fall by 62% between 2009 and 2015 (*Figure 12*). Continued cost reduction potentials are large, and with continued rapid growth in solar PV deployment to between 1 750 GW and 2 500 GW by 2030 (IRENA, 2016a), the central case examined here identifies that the global average total installed cost of utility-scale PV systems could fall from around USD 1.8/W in 2015 to USD 0.8/W in 2025, a 57% reduction in 10 years (IRENA, 2016b). Taking into account the range of uncertainty around cost drivers, the decrease could be anywhere between 43% and 65% from 2015 levels. The majority (about 70%) of the cost reductions are expected to come from lower BoS costs.

However, installed cost ranges vary widely depending on the market, its maturity, structural factors (*e.g.*, unit labour costs, commodity prices, etc.) and the regulatory framework (*Figure 13*). The data show the range in average installed costs by country for residential systems and the 5th and 95th percentile of project data for utility-scale systems from the IRENA Renewable Cost Database. The residential cost range in Figure 12 masks even wider cost ranges for individual systems in specific countries.[15] What is clear from this analysis is that cost variations within countries and between countries can be significant, and that a detailed understanding of these reasons is often not available, although increasingly research is working to correct this gap in knowledge.

15 See *Renewable Power Generation Costs in 2014* (Anon., n.d.) for a more detailed discussion. As an example, in 2014, the median installed cost for a residential solar PV system in California was USD 5/W, but the 5th percentile was at USD 3/W and the 95th percentile at USD 6.5/W. This range of USD 3.5 between the 5th and 95th percentiles was significantly lower than the 2011 figure of USD 7.7/W, when median installed costs were USD 7.3/W.

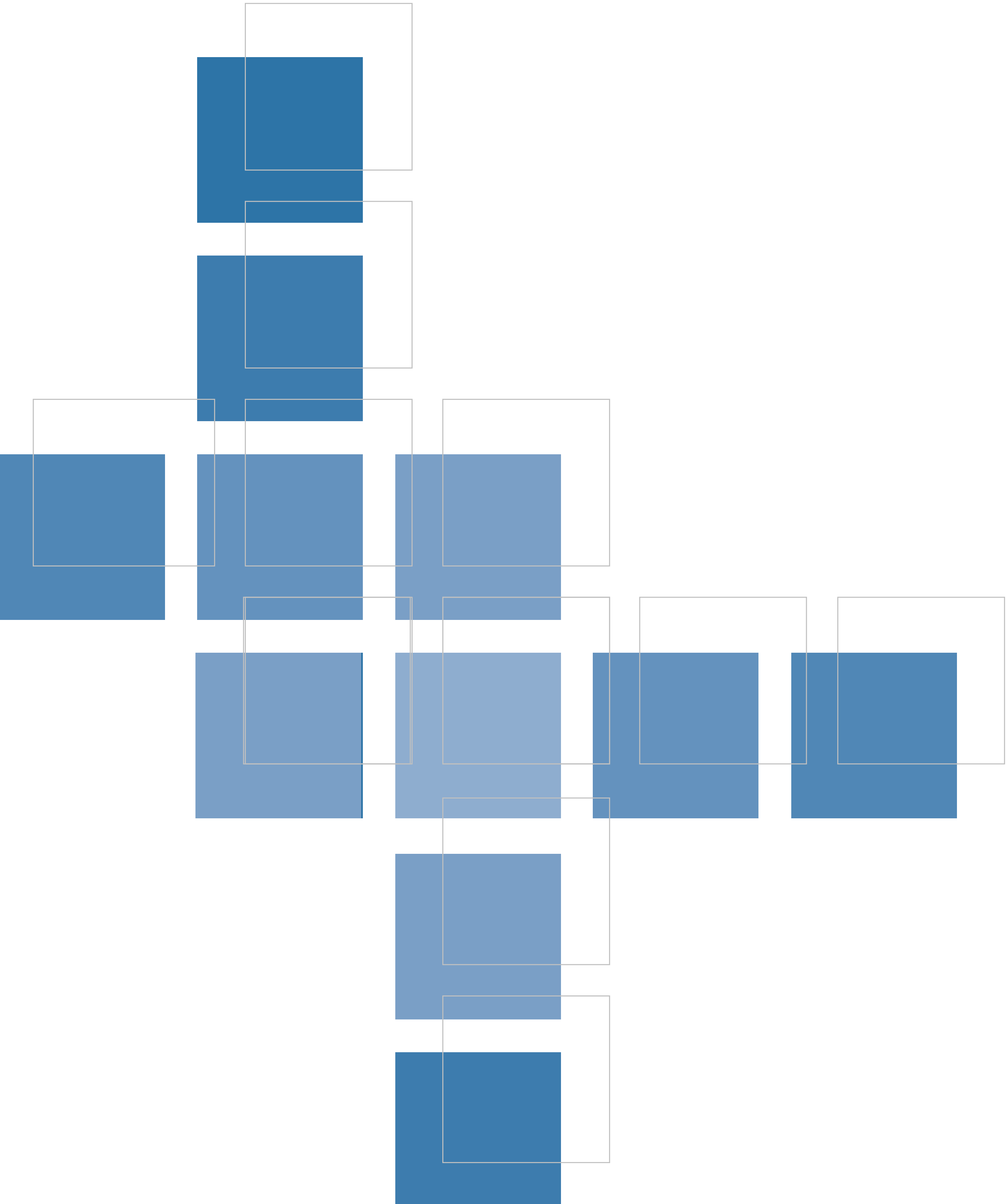
Figure 13: Installed cost ranges for residential and utility-scale solar PV in major markets, 2009-2015



This cost variation for solar PV has important ramifications for trying to identify what a reasonable cost structure might look like in new or emerging markets, such as the situation in Africa today. It is clear that country-specific factors can, and do, have a significant impact on not only cost structures in new markets, but also the total installed cost level. At the same time, although all markets have experienced cost reductions in recent years as both module prices and BoS costs declined, significant installed cost-level differences remain. Convergence in costs in many markets (*e.g.*, the United States compared to Europe) has been only partial, implying that it is not simply a question of market maturity, but that structural and regulatory frameworks have an impact on what efficient cost structures for solar PV in different markets will look like.

The implications for Africa from these observations and analysis are significant. They highlight that a large gap can exist between what a hypothesised "efficient" cost structure in African countries may look like and what is actually achievable on the ground given local market maturity, structural cost factors and the impact of the regulatory framework. There is a tendency among many commentators and researchers to be overly optimistic about what average solar PV installed costs may look like in Africa (and indeed elsewhere), particularly for small-scale projects and residential systems, as deployment grows. The difficulties of rapidly establishing an efficient cost structure given all of the challenges involved can be large. This is not to say that they are unreasonable assumptions for a longer-term, more established market situation, but that there often is a tendency to underestimate initial levels.

This is important, because a pronounced mismatch between assumed costs and likely starting cost structures can mean that policy support settings or expectations can be unrealistic. This can have serious consequences for deployment and political support for solar PV, as initial expectations are not met. Therefore a better understanding of likely cost structures for new markets can be a valuable tool in setting realistic expectations and achievable deployment and cost reduction goals.



5 SOLAR PV COSTS IN AFRICA

Historically, the development of new solar PV markets has required a period of learning before installed costs decline to "efficient" levels, taking into account structural factors that mean that costs will not converge to the same level in all markets, even after markets become mature. What has been encouraging as the global market for solar PV has grown is that the time it takes to reduce costs to more efficient levels appears to be falling. The recent announcements of successful tender results or power purchase agreement (PPA) prices in Mexico (an average of USD 0.045/kWh) and Dubai (USD 0.03/kWh) provide compelling examples of this trend. The Dubai result is particularly interesting, as it comes approximately a year and a half after Dubai set the then record of USD 0.059/kWh. Africa now has its own example, with Zambia's recent announcement of a contract for solar PV at USD 0.06/kWh under the World Bank's Scaling Solar programme.[16]

Senegal and Madagascar also are participating in the Scaling Solar programme, although it remains to be seen whether, without the assistance of these types of programmes, a trend to rapid low-cost PPAs can be extended to sub-Saharan Africa, given the challenging business environment in some parts of the continent. However, it is exciting to see that despite the very early stages of utility-scale solar PV deployment in Africa, and given the transportation and engineering challenges facing infrastructure projects on the continent, it already is possible for projects to have competitive total installed costs and cost structures compared to the global average.

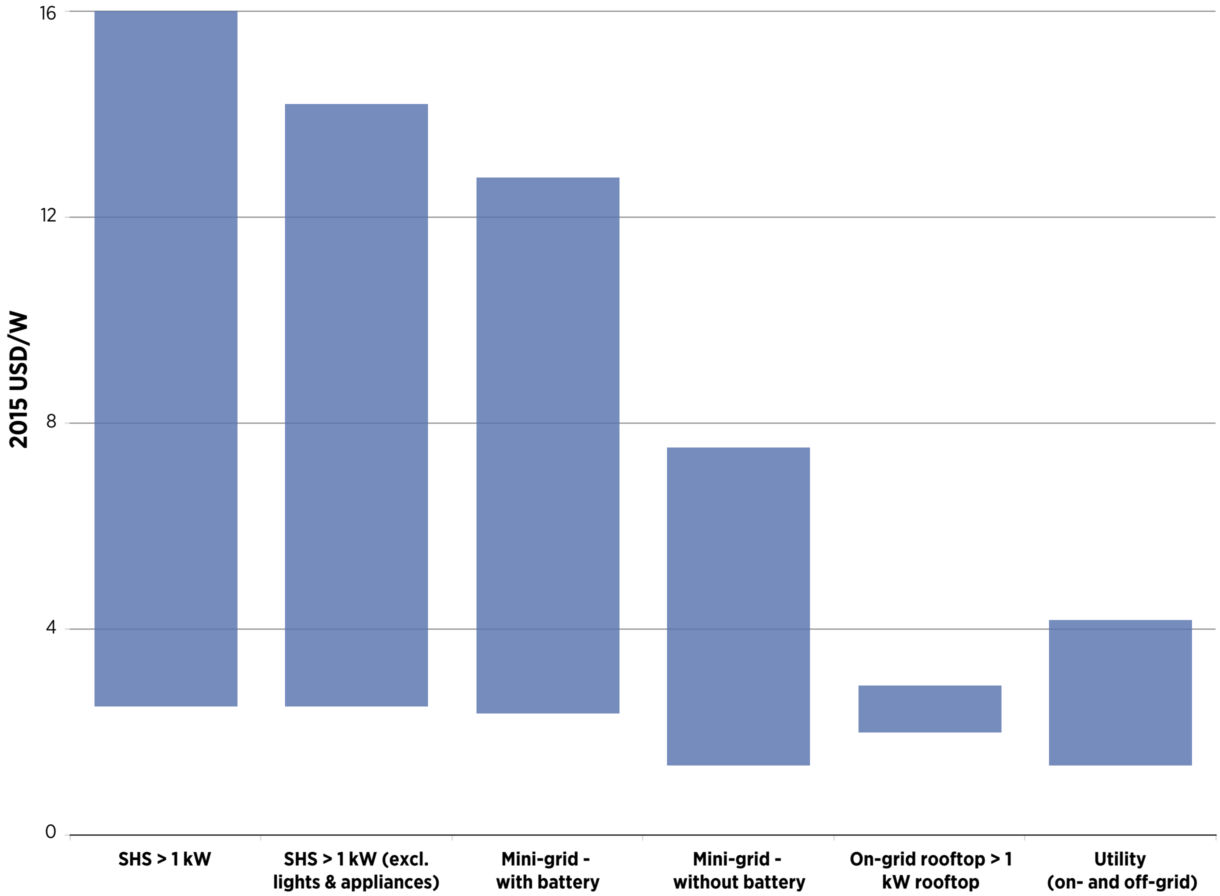
Utility-scale projects in 2015 had estimated costs of between USD 1.35 and USD 4.1/W, while projects for 2016 and beyond are targeting a narrower range, with the majority of projects between USD 1.4 and USD 3/W (Figure 14). This compares to a global average in 2015 of USD 1.8/W for utility-scale projects. These low cost structures are being targeted not just in the more developed North African countries and South Africa, but in a range of sub-Saharan countries. The key constraint on these low cost structures is that they are likely to be achievable only close to major ports where transport costs are low and where access to experienced civil engineering expertise is possible. It remains to be seen whether these cost structures are feasible more widely in sub-Saharan Africa and also to what extent they are replicable in the interior.

At the other end of the spectrum solar home systems less than 1 kW in size have the added expense of batteries and virtually no economies of scale. They therefore are considerably more expensive and experience a wide variation in costs, with total installed costs of between USD 4.3 and USD 14.2/W (for 18-136 W SHS). These systems are all DC systems that utilise LED lights and provide charging for mobile phones and, for the larger systems, provide the ability to run small appliances for short periods, representing the largest portion of the SHS market.

AC systems are more expensive, require an inverter and typically are larger. The IRENA database contains cost data for systems between 200 W and 750 W. Costs for these niche systems are consistently higher than for the smaller systems and fall between USD 14 and USD 23/W, a level driven in part by the inverter costs and by the costs of the larger, more capable batteries that are installed with them. As such, although they are more expensive, they also are more capable systems and can provide a wider range of energy services. The installed costs of SHS with more than 1 kW of capacity range from between USD 3.6 and USD 17/W for the data available. Grid-connected

16 The programme offers financing, insurance and advisory services and significantly reduces development risk, thus attracting some of the strongest developers and making very competitive bids feasible by reducing or eliminating exchange rate, offtake and country risks.

Figure 14: Solar PV cost ranges in Africa by market segment and size, 2009-2016



Source: IRENA Renewable Cost Database, 2016

rooftop systems in the larger than 1 kW size range have lower costs, between USD 2 and USD 3/W in 2015, although these systems are concentrated in North Africa and South Africa.

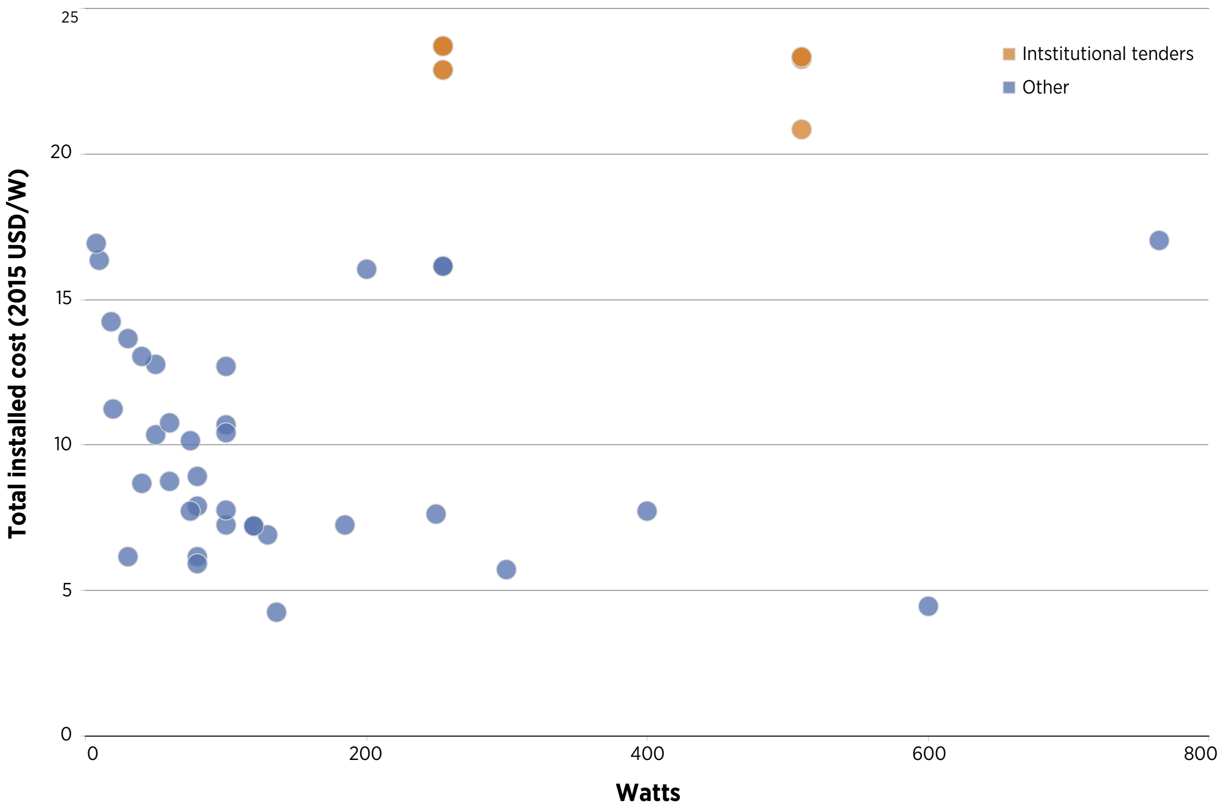
The cost range for mini-grid systems (without batteries) that are connected to the grid[17] is somewhat higher than the current range for grid-connected utility-scale systems and is around USD 2.5 to USD 2.9/W for projects in sub-Saharan Africa. The data that IRENA has collected for solar PV in off-grid mini-grid systems that do not have batteries are for systems installed in North Africa that have lower installed costs, from USD 1.4 to USD 2.7/W. For mini-grids relying more heavily on solar PV, where a battery is included, the total system cost can be double or triple that of mini-grids without batteries, with a range of between USD 2.5 and USD 10.9/W. This represents the fact that many of these systems are greenfield in nature and have higher project development costs, in addition to the costs associated with batteries.

17 These types of mini-grids typically are at educational or other large institutions, industrial sites, mines, etc. They can operate in isolation or with electricity flowing to or from the grid. Most of these systems rely on oil-fired generation, and the incorporation of solar PV can help reduce costs.

Solar home system costs (<1 kW)

Solar home systems and grid-connected rooftop solar PV systems can be implemented in Africa not only in rural areas with large non-electrified areas and populations, but also in grid-connected urban areas, which in sub-Saharan Africa are increasingly suffering from frequent power shortages and outages. SHS and grid-connected rooftop solar can help to reduce pressure on the grid by lightening the load of household and commercial power demand from the national grid, as well as meet the basic energy services of those without access to electricity today.

Figure 15: Small solar home system (<1 kW) costs by system size in Africa, 2012-2015



Source: IRENA Renewable Cost Database, 2016

The small sub-1 kW size group of SHS has a very wide range of total installed costs, from a low of USD 4.3/W to a high of 17/W for most systems, with a cluster of systems between USD 6 and USD 14/W. The majority of the SHS sold in Africa today are believed to be in the 20 W to 100 W range. At this scale, manufacturer, distributor and/or retailer margins have a significant impact on the total costs of the system. Total costs for systems of 20 W to 100 W in size therefore span a wide range. The cheapest 20 W system was found to cost around USD 225, while for a 100 W system the total cost ranged from USD 725 to USD 1 270.

The smallest of these systems is very basic and provides enough power for a couple of lights for several hours. The larger systems can provide lighting for an extended period and also can provide charging for a mobile phone, although some trade-offs are required. It is worth noting that the system specifications of individual SHS can vary widely, with inexpensive entry-level systems offering smaller battery storage capacity to reduce costs and increase affordability. Below 100 W the systems are relatively homogeneous, focusing on low upfront costs. However, at around 100 W or greater product differentiation begins, with a range of systems with greater or lesser capability based on battery size and service provided (*e.g.*, mobile phone charging docks, small radios, etc.).

In Figure 15, the orange dots represent the total installed cost of small institutional systems procured through tenders. It would appear that tendering for relatively small numbers of identical small-scale systems results in significantly higher total system costs for these smaller systems. This is likely due to additional administrative costs for promoters in entering the small-scale tenders and perhaps also to the geographic dispersion of the systems (*e.g.*, 10 to 50 small-scale systems for remote locations) driving up per unit costs on these very small systems.

Another interesting finding in this category is that the big suppliers of solar systems have a more structured cost escalation for size growth compared to the small suppliers. For the data available, small suppliers tend to charge the same amount for different sizes of systems below 1 kW in several

BOX 2:

The difficulty of comparing costs for SHS in Africa with other residential solar PV system benchmarks

SHS are used by households in Africa and elsewhere to provide modern energy services. They are small systems, with typical capacities of 20 W to 100 W, that provide off-grid electricity services. In contrast, in OECD countries small-scale solar PV rooftop systems are almost always grid-connected rooftop systems in the 1 kW to 20 kW range. It is not meaningful to compare the costs of the two, as the results would be very misleading. The scale, purpose and configuration of the systems all differ significantly.

For instance, SHS often deliver only DC power, with no need for an inverter but requiring an expensive battery for nighttime use. This DC system directly powers the system's electrical load, generally highly efficient LED lights and/or other small DC-powered appliances, such as radios, televisions, mobile phone charging ports and USB chargers. Solar PV rooftop systems in the OECD complement the grid by providing AC power through inverters for either self-consumption or export to the grid.

The scales of the systems also are dramatically different. Compared to African SHS, some of the larger OECD rooftop solar PV systems on residential houses would seem more like utility-scale projects, with sizes 30 to 1 000 times larger than that of an African SHS. Clearly, even though these are small systems, the economies of scale of the larger OECD systems and the absence of batteries means that per watt costs will be significantly higher for the small SHS used in Africa.

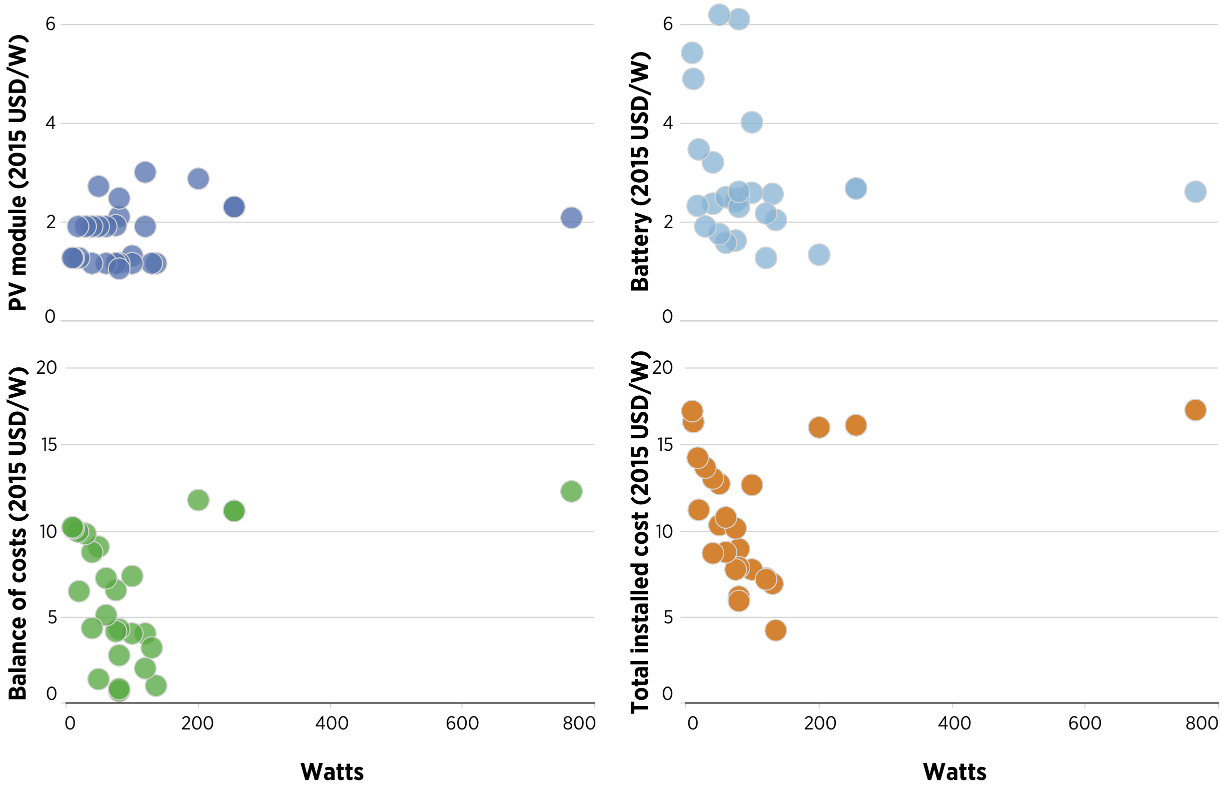
As a result, it is only really meaningful to compare the per watt costs of SHS to their direct peers, or alternatively, to calculate the cost of the energy services provided and compare that to the existing costs that Africans pay for energy services off-grid. This is an area where further work is merited, as the rapid declines in solar PV costs mean that previous analyses are often out-of-date.

countries in Africa due to high administrative costs (marketing and procurement costs) which must be covered regardless of the size or the location of installation. Alternatively, larger suppliers appear to tailor their costs to highlight that small-scale systems do not have the same (modest) economies of scale as the larger sub-1 kW systems. It is not clear whether this is the result of large programmes with government or rural electrification authorities, where purchasers would expect to see economies of scale, or is due simply to the larger volumes that these companies distribute (sometimes across different African markets). In any event, larger distributors have lower system costs compared to those of small suppliers for larger systems in this size category. This tendency was particularly noticeable in Tanzania and Ethiopia.

The variation of the breakdown costs for individual systems is quite high, but the variation is not the same for all components. Figure 16 provides an overview of the cost distribution of SHS components depending on the system size for sub-1 kW systems. The PV module costs span a significant range but cluster around USD 1.2 and USD 1.9/W. Battery costs show a significantly larger variation in installed costs; however it is the balance of all other system costs that show the largest variation.

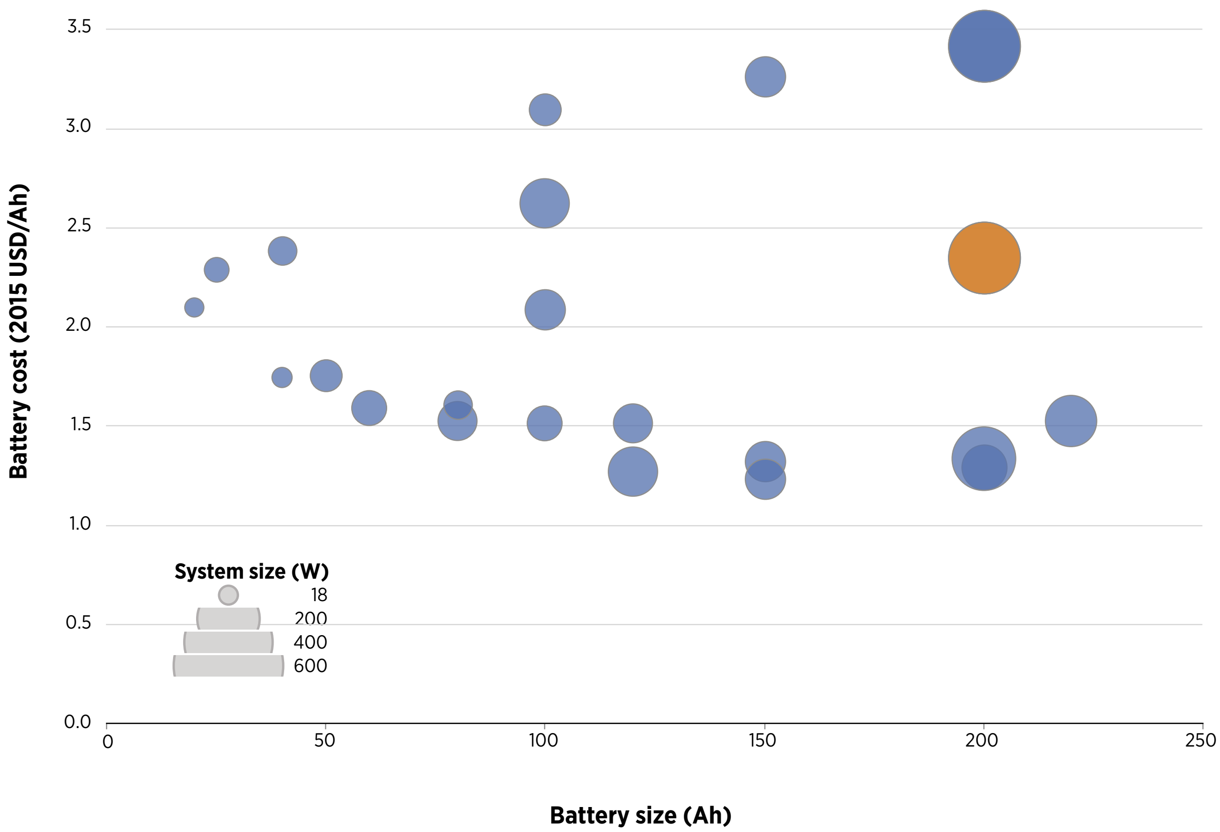
Figure 17 goes some way to explain the variation in the battery costs seen per watt of installed solar PV, as it shows that the cost per Ah (a measure of the capacity of the battery) can vary by a factor of two or more. The costs for batteries in these systems vary between around USD 1.2 and USD 3.4/Ah. All of these SHS for which data are available utilise either simple lead-acid batteries, or deep-cycle lead-acid batteries, with no clear cost distinction between the two with data available. That said, there is a clear trend to lower total installed costs per watt as the battery size and solar PV capacity grows, although for the data available this levels off for battery sizes of 100 Ah and above. There

Figure 16: Cost distribution of SHS components relative to system size for sub-1 kW systems, 2014-2015



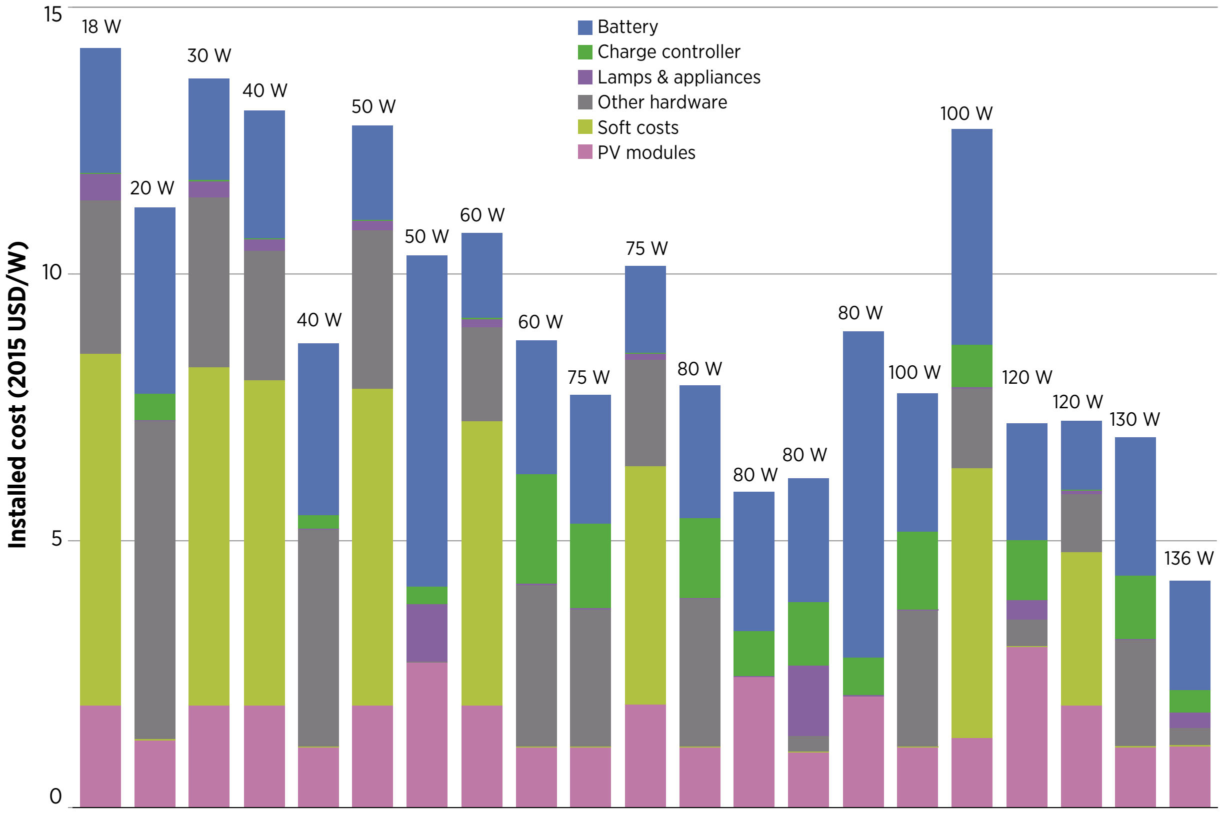
Source: IRENA Renewable Cost Database, 2016

Figure 17: Solar home system battery costs relative to battery size and PV system size in Africa, 2012-2015



Source: IRENA Renewable Cost Database, 2016

Figure 18: Small solar home system (<1 kW) cost breakdown by cost component, 2012-2015



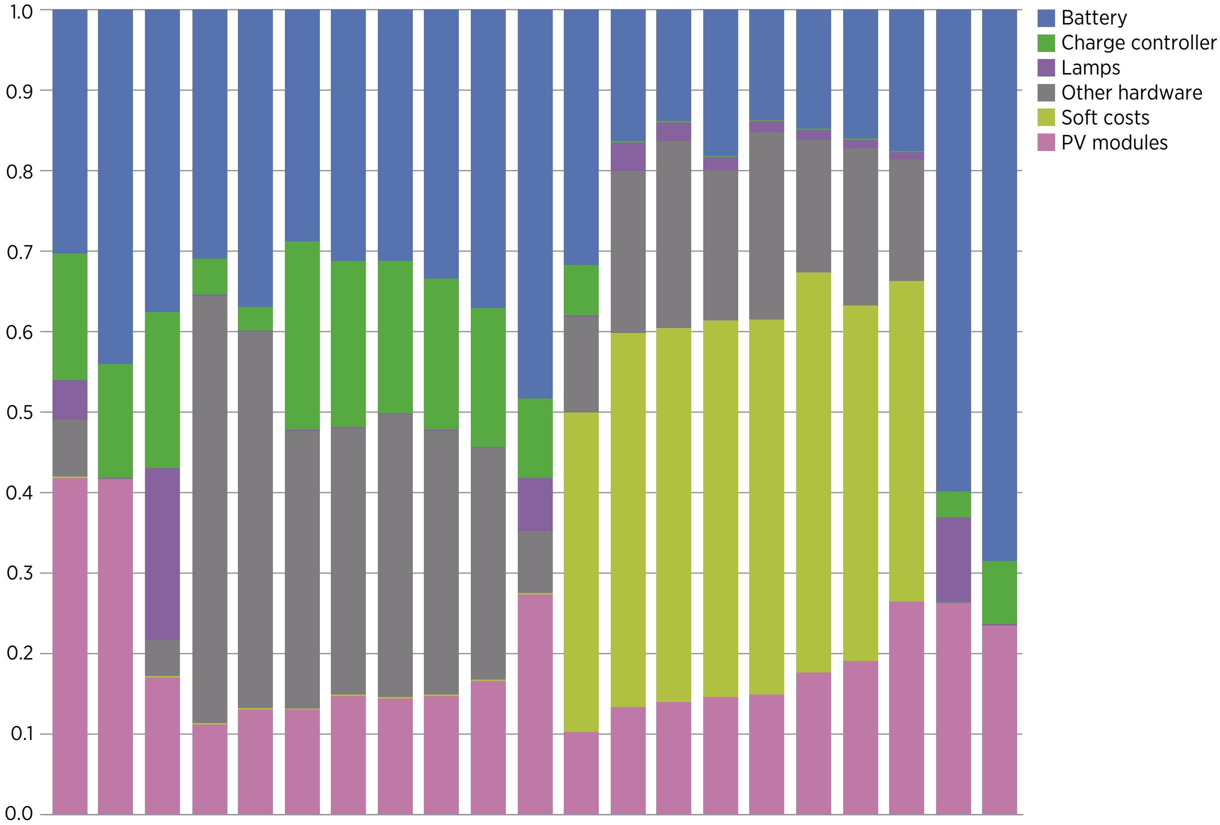
are several outliers to this analysis, with high costs for the battery relative to the trend in some cases.

Figure 18 presents the cost breakdown for sub-1 kW SHS where the data are available. Battery costs account for the largest single share of these SHS, with a simple average of 29% of the total costs (USD 2.7/W). The PV modules themselves, as well as the lighting fixtures and wiring, average around 20% (USD 2.2/W) of the total installed costs together, soft costs for 22% (USD 2/W), other hardware for 21% (USD 2/W) and the charge controller for 7% (USD 0.7/W). There is a reasonably clear correlation in Figure 18 between increasing SHS size in terms of the module capacity and lower specific costs per kW, although given that the dataset is not necessarily a representative average, care must be taken in interpreting the strength of the relationship.

The lack of cost-breakdown availability, or gaps between the total cost and the sum of cost components, can be understood as a poor understanding by the respondents of their own costs, either because of challenges with their accounting system or because they were purchasing off-the-shelf systems at fixed prices for their businesses. It also is possible that respondents prefer to keep their cost details confidential. The cost breakdown per system illustrated in Figure 18 shows that 8 out of the 21 data sets indicate soft costs (installation cost, customer acquisition, marketing costs, etc.).

Figure 19 presents the same data, but in percentages to show the range of cost shares. Battery costs accounted for 14-69% of total installed costs, soft costs (where reported) for 40-50%, other hardware for 4-53%, PV modules and lights for 10-47% and the charge controller for 3-23%. Grouping the PV modules, battery and charge controller costs on average accounts for 55% of the total installed costs, with a variation of between 29% and 88%, except in two cases, where no other costs were specified. It is important to note that many respondents were not able to break out all of the cost categories, the most common issue being soft costs already apportioned to hardware categories or, in some cases, the "other hardware" category being used to cover undefinable extra costs.

Figure 19: Small solar home system (<1 kW) cost component shares, 2012-2015



The battery makes up a significant cost component of these sub-1 kW SHS. The battery generally also has the shortest lifetime of any component, adding to its contribution to the lifetime cost of the product. While modules and LEDs will last 10-20 years or more, batteries often last 5 years or less and can require more maintenance. Battery replacement therefore will be an important component of the lifetime costs of SHS.

In addition to the project- and programme-level data, average values sometimes are reported. Kenya currently does not have value-added tax (VAT) for solar PV components, but part of the data comes from the beginning of 2014, after which the government shortly introduced a 16% VAT. The Kenya Renewable Energy Association also pointed out that, "The average solar PV system size for households in Kenya is 25-30Wp. The typical cost of installed systems is about 12 USD/Wp installed" (KEREA, n.d.).

At the distributor level, price data for SHS provide useful insights into the different capabilities and costs of different systems. Table 5 presents system prices from one supplier in Uganda. The data indicate that as the size and capability of the system increases, so too do average costs, driven predominantly by the increased battery costs. Total installed costs will be higher than these values, because they do not include the seller's margins, transport and installation costs.

Table 5: Solar home systems package price in Uganda

Size (kW)	Battery	Cost (USD/kW)
0.3	2 x 12 V/ 100 Ah	1 731
1	2 x 12 V / 150 Ah	2 692
1.5	2 x 12 V / 230 Ah	3 269
3	8 x 6 V / 220 Ah	6 154

Source: IRENA Renewable Cost Database, 2015

Many of today's SHS are being sold on a pre-paid business model. Different packages are typically available with several classes of price and system capability. SolarNow in Uganda, for example, offers packages such as the following:

- 50 W system with 3 lights, mobile charger and a radio for USD 24 per month with USD 128 deposit
- 100 W system with 6 lights, a radio and a DC LED TV/DVD for USD 51 per month and a USD 260 deposit
- 100 W system with 3 lights, a 300 W AC inverter for USD 45 per month with a deposit of USD 238
- 250 W system with 15 lights for USD 85 per month with a deposit of USD 431.

Similar pre-paid models are being implemented broadly in Kenya, Tanzania and Uganda by M-KOPA SOLAR, and in Ghana by PEG Ghana Solar.

BOX 3

SHS are an economical solution to the electrification challenge in Africa

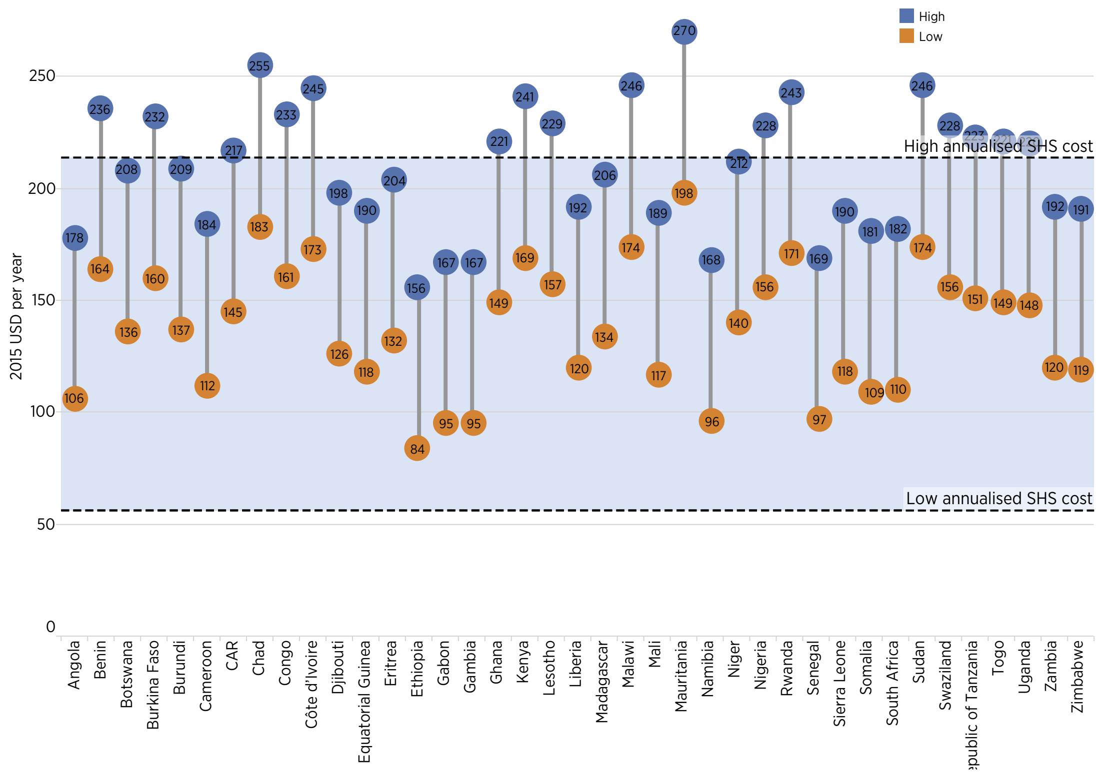
The relatively high costs per watt for sub-1 kW SHS in Africa are misleading when it comes to just how economic a solution they are for providing electricity access to the approximately 600 million Africans who still lack access to electricity. Unlike for their larger counterparts, calculating an LCOE for these smaller systems is close to meaningless, as there may be no grid-connected electricity system price against which they can be compared, and these users cannot afford their own diesel generators. When determining the relative economics of these SHS it makes more sense to examine the energy services they can provide in relation to existing energy services being demanded by households off-grid and their costs.

Currently, off-grid households in Africa are estimated to spend anywhere between USD 84 per year (in Ethiopia) to USD 270 per year (in Mauritius) for lighting and mobile phone charging (BNEF, Lighting Global, World Bank and GOGLA, 2016; IRENA analysis). For lighting, off-grid households use candles, kerosene lamps or battery-power torches. These often provide very low-quality lighting services at significant cost per kWh of useful illumination, and can contribute to indoor air pollution with its associated negative impacts on health.

Individual SHS systems have total installed costs for a 20 W system of around USD 225, while for a 100 W system the total cost ranged from USD 725 to USD 1 270. Taking the conservative assumption that these SHS last just six years and require one battery replacement yields annual costs of USD 56 to USD 214/year, assuming a 5% real cost of capital. Given estimated annual expenditures today for off-grid lighting and mobile phone charging of between USD 84 and USD 270 per year, SHS can represent a very economical solution (Figure 20)

This is before taking into account any reduced transport costs for trips dedicated to mobile phone charging, which can amount to USD 25 per month in some cases (GSMA, 2011). The analysis also does not take into account the improvement in the quality of energy services provided by SHS using LED lights. For instance, a 2 W LED light will produce around 380-400 lumens of light compared to 8-40 lumens for a kerosene wick lamp. The price per unit of useful light (lumen) provided of SHS therefore can be one-third to one-hundredth of the equivalent light from a kerosene wick lamp. This analysis also does not take into account the health benefits of reducing indoor air pollution.

Figure 20: Annual off-grid household expenditure on lighting and mobile phone charging compared to SHS (<1 kW) annualised costs, by country in 2015



Source: BNEF and IRENA, 2016

Solar home system costs (>1 kW)

For the larger SHS and rooftop solar PV systems which exceed 1 kW in size, there is a similar upper limit for costs, with a range of between USD 2.5 and USD 16/W for off-grid SHS and a range of between USD 2 and USD 2.9/kW for on-grid rooftop solar systems without storage (Figure 21). For these larger systems, there is a clear difference between the competitive costs in some markets which see the availability of SHS with batteries in the sub-USD 5/W cost range and the more expensive markets, which are either more remote or smaller in scale and have costs clustered between USD 8.3 and USD 16/W. The lower cost range highlights that in the right circumstances, cost structures for new and small markets can be competitive.

The installed costs for the on-grid products examined, which do not have the additional expense of batteries and charge controllers, are comparable to what was experienced in the more competitive global markets in 2014 and 2015, and represent a very economic option for Africa with its excellent resource quality. However, most systems and programmes for which data are available suggest a poorer cost structure, representing the small scale of local markets and the necessity to import virtually all of the system components.

Figure 22 presents the cost breakdown where the data are available. Compared to the sub-1 kW SHS, there are better cost-breakdown data. In particular, the “rest of hardware” category is less pronounced and appears not to have been used as a catch-all for unallocated project costs, with a more representative allocation to all other costs. What is interesting in this sample is the absence of data about inverter costs. It is possible that these have been bundled with the PV modules

FIGURE 21: SOLAR HOME SYSTEM (>1 KW) INSTALLED COSTS, 2012-2014

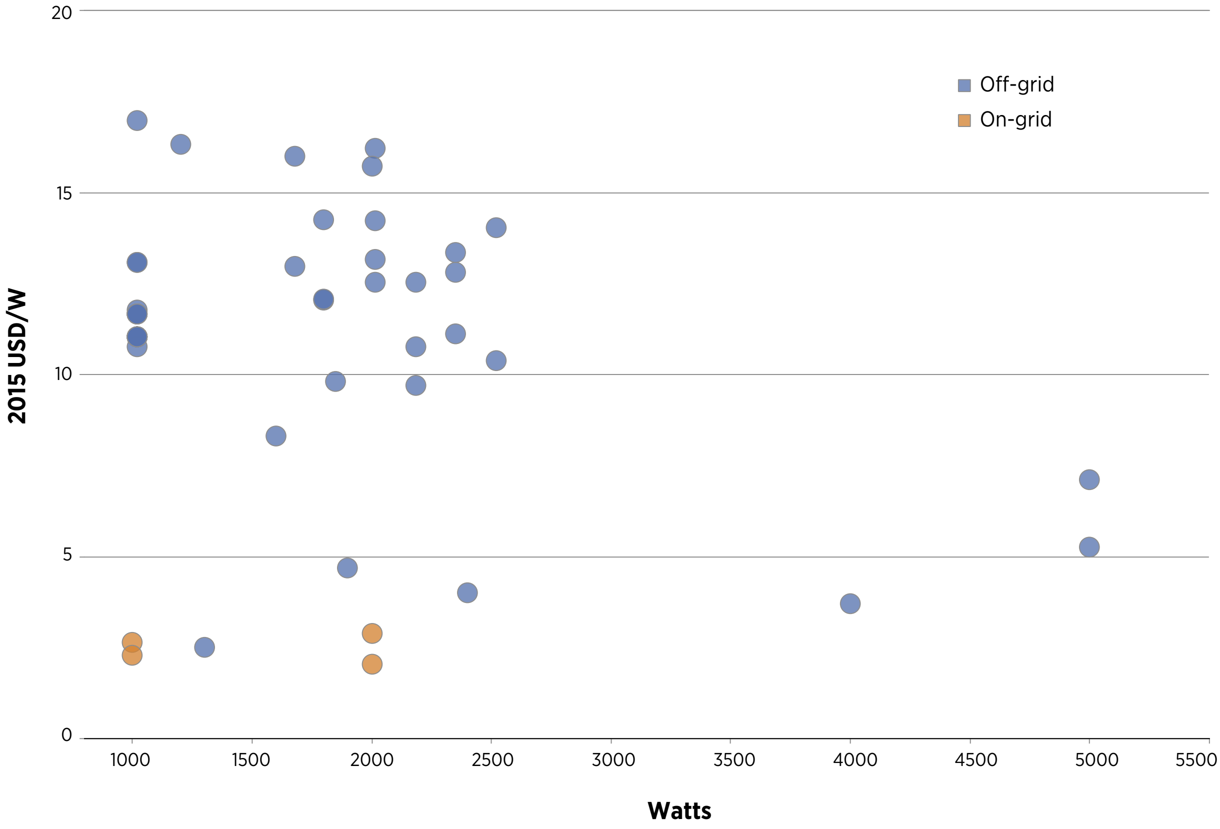
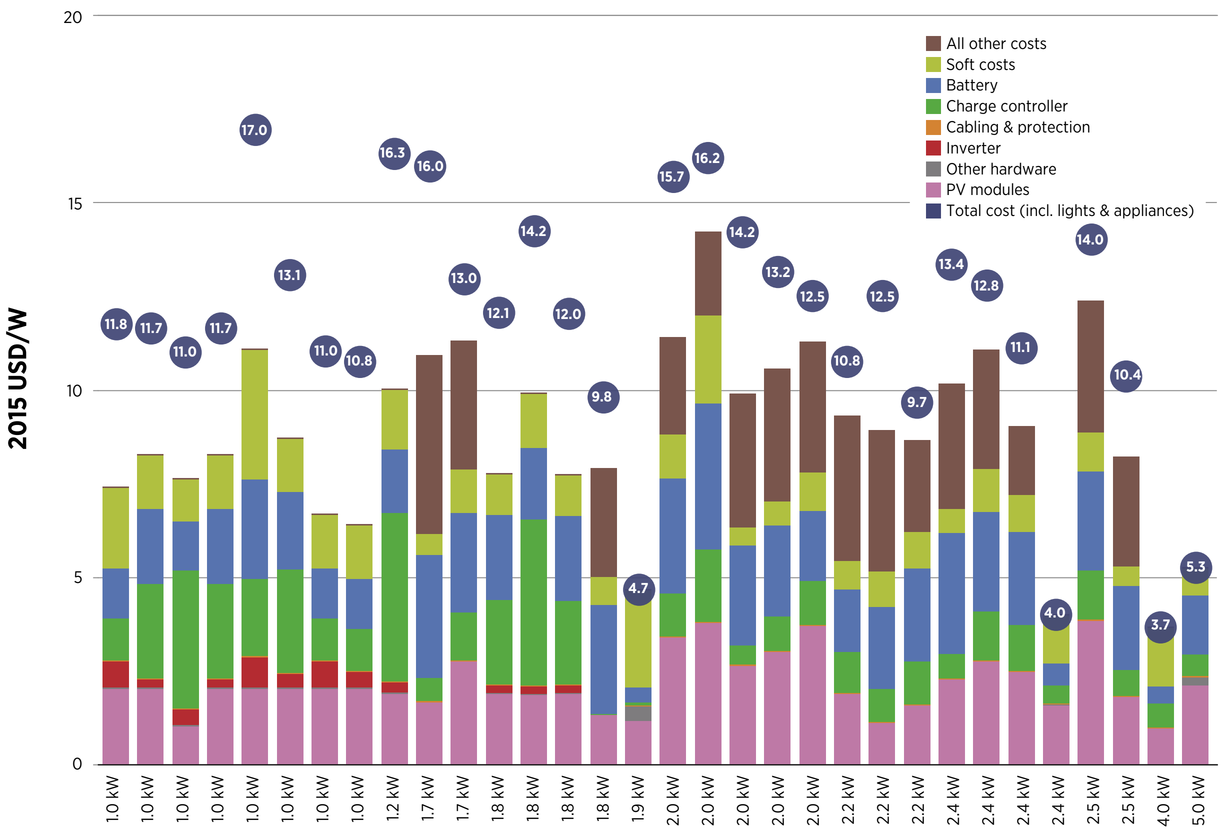


FIGURE 22: SOLAR HOME SYSTEM (>1 KW) COST BREAKDOWN BY COST COMPONENT, 2013-2014



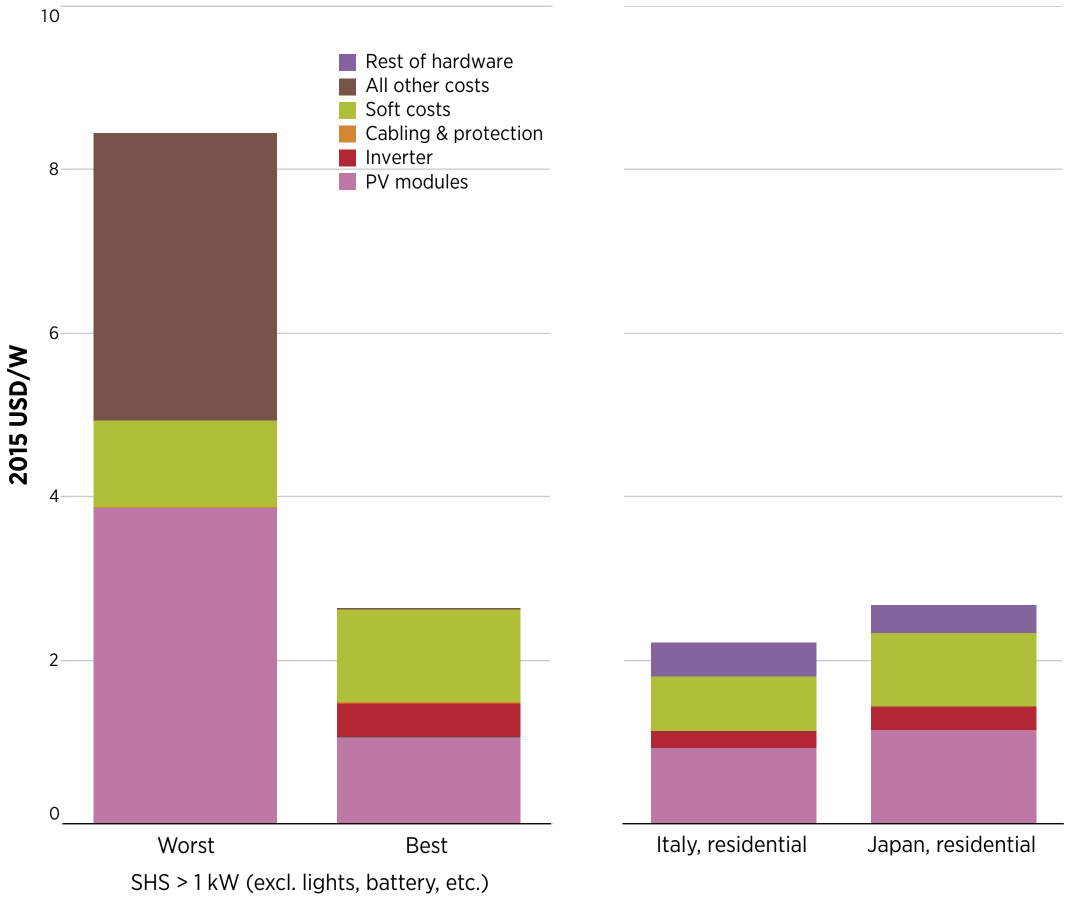
BOX 4

Benchmarking large SHS cost structures in Africa with residential solar PV system costs in other markets

Although it is not useful to directly compare the total installed costs of sub-1 kW SHS in Africa to other markets, an idea of the current relative competiveness of the different cost components is useful in order to gauge the potential for cost reductions. It is important to bear in mind that it will be difficult, if not impossible, to achieve similarly low-cost structures comparable with what is possible in countries with stable regulatory and policy frameworks, well-developed financial markets, excellent civil engineering, infrastructure and well-established local supply chains for solar PV. None of these are the norm in sub-Saharan Africa, where many of these conditions do not exist.

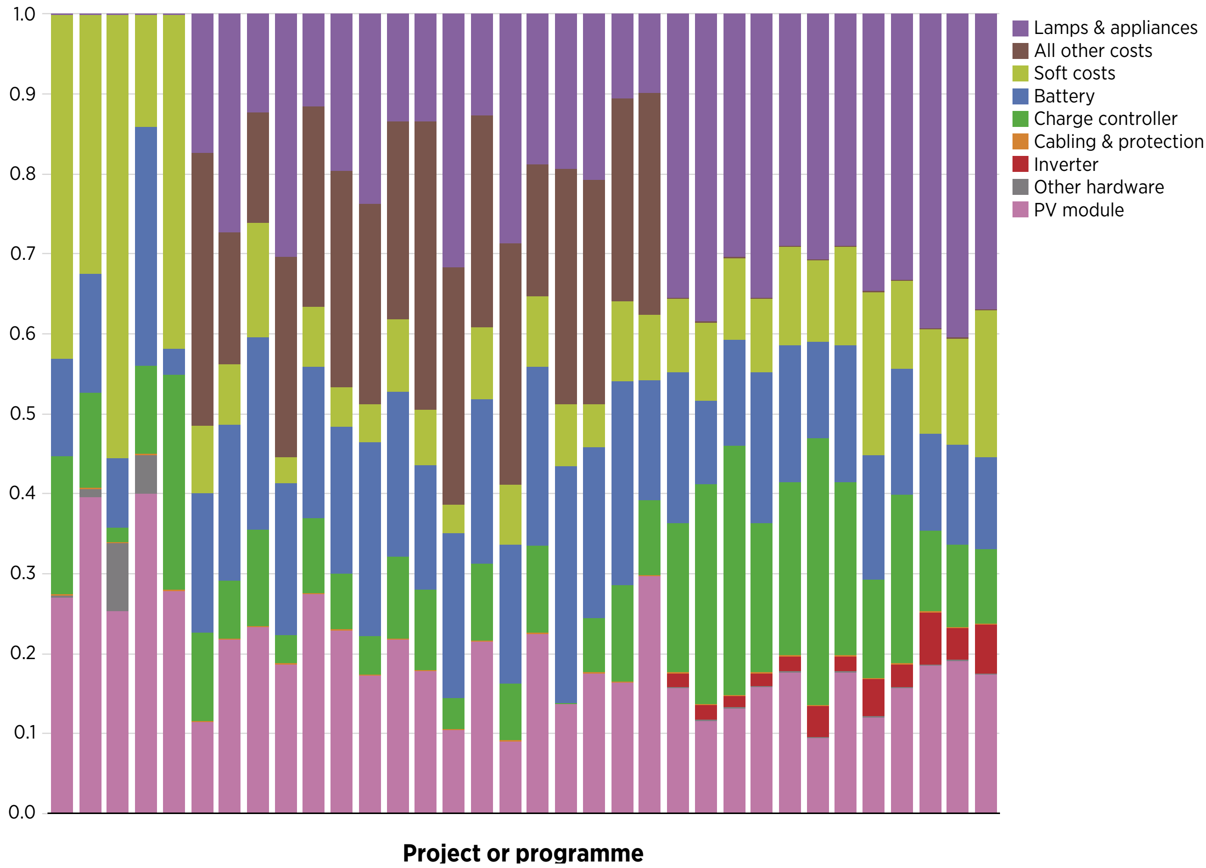
Taking into account these caveats, Figure 23 highlights today's cost structure for SHS greater than 1 kW, excluding the off-grid components (*e.g.*, battery, charge controller, lamps and appliances). Removing these items, which are not required in grid-connected residential systems in OECD countries, removes cost components that account for 35% to 52% of the total costs. This somewhat artificial comparison reveals that the cost structure of the most competitive large SHS in Africa compares relatively favourably to higher-cost OECD markets in the best circumstances. However, in the most expensive African markets, the cost components in common with OECD rooftop solar PV systems are at least three times higher than in the Italian market for instance. This highlights the importance of the structural differences in costs; when systems are installed off-grid in remote locations where basic infrastructure can be almost completely absent, costs inevitably will be high.

Figure 23: Solar home system (>1 kW) cost breakdown in Africa and rooftop solar PV costs for Italy and Japan (excluding off-grid components), 2013-2014



Note: Data for Africa are for 2013 to 2015, and the average excludes projects for which a full cost breakdown is not available. Data for Italy, Japan and the United States are for 2014. Residential system size for Italy is below 10 kW, Japan is 3-10 kW and the United States is 1-10 kW.

Figure 24: Solar home system (>1 kW) cost breakdown shares, 2013-2014



themselves in some cases, as not all respondents specified whether these were AC or DC systems.

What is interesting about many of these systems, particularly in the sub-2 kW range, is that they are sold with lamps and appliances that make up a significant portion of the total cost. A simple average of these projects is around USD 11.5/W; however, excluding the 21% (USD 2.7/W) average cost of the lights and appliances reduces the average to around USD 8.8/W. The lights and appliances increase the total installed cost of these SHS by 11% to 68% depending on the system. It is notable that systems sold without these components have substantially lower costs of between USD 3.7 and USD 5.3/W, suggesting that there may be a degree of opacity in the pricing of systems with appliances that allows for higher margins, although the data are not sufficiently robust to be sure of this.

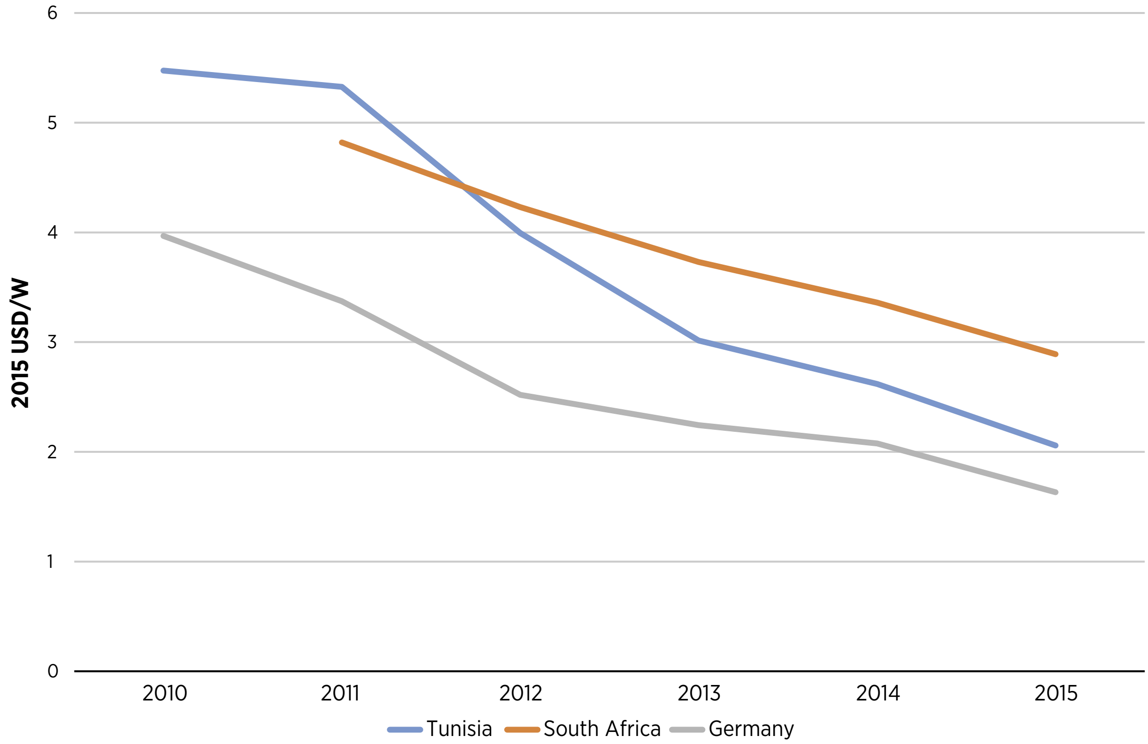
The next largest cost share is that of the PV modules (19%) and battery (around 18%), accounting for on average around USD 2/W. Soft costs accounted for on average 16% of total costs, and the charge controller and other costs for around 13% each of the total.

Grid-connected rooftop solar PV in Africa

Most of the grid-connected residential solar PV systems in Africa are installed either in North African countries or in South Africa. Tunisia and South Africa in particular have established markets, while Morocco has successfully used solar PV to electrify villages. These markets have competitive costs compared to OECD countries.

In Tunisia, the government initiated the PROSOL-Elec programme in 2010. This programme aims to support the development of solar PV connected to the national grid network, especially in the residential sector. A key aspect of the programme lies in its innovative financing mechanism, which combines investment grants and loans. The programme is called "suivantes7 incentives" and the financing programme consists of a grant from

Figure 25: Comparison of average total installed cost of residential solar PV systems, 2010-2015



Note: Data for Tunisia for 2015 are IRENA estimates.

the National Energy Management Fund (FNME) for 30% of the investment cost of a solar PV system. This grant is capped at USD 920/kW (1 800 DT/kWp) for system sizes up to 1 kWp and USD 740/kW (1 450 DT/kWp) for higher-capacity systems, with a maximum grant per system of USD 7 650 (15 000 DT) (GIZ and ANME, 2013).

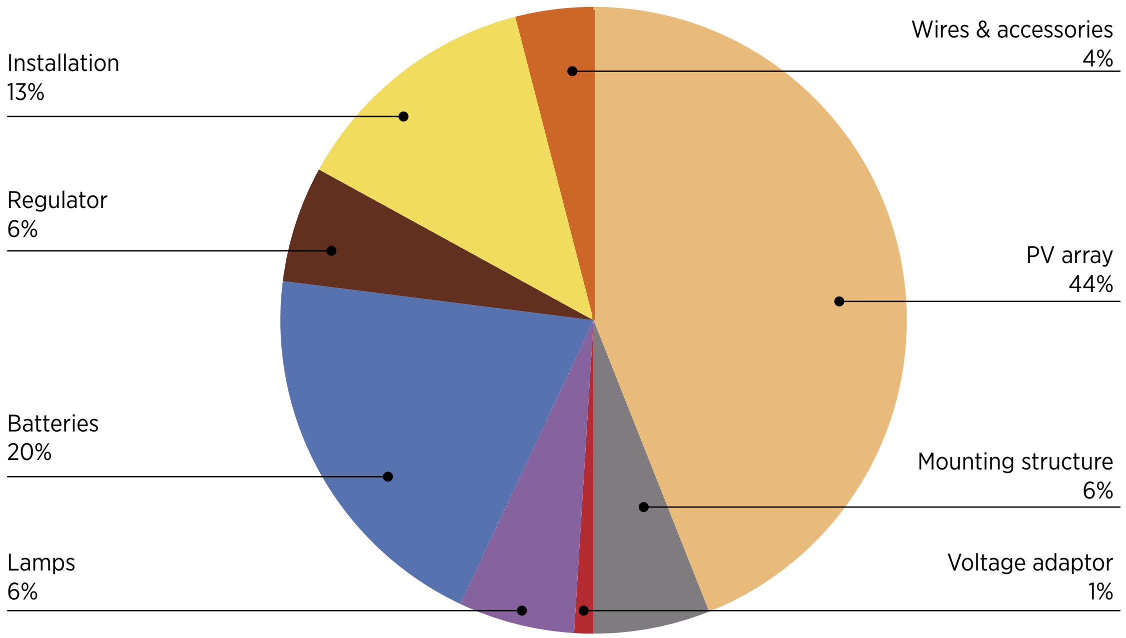
In 2010, the average cost for residential systems in Tunisia was around USD 5.5/W, but costs had fallen to USD 2.6/W by 2014; data for 2015 are not finalised but are estimated at around USD 2.1/W. However, like in many countries average costs varied significantly, with a factor of 2.2 between the cheapest and most expensive systems. This large price distribution suggests a lack of competition and no transparency indicator for customers (GIZ and ANME, 2013). In those years only 4 out of 41 providers engaged in international sourcing of panels, as Tunisia has a tax-exemption policy for locally produced solar modules. Between 2010 and 2015 the average price of rooftop solar PV in Tunisia declined from being 37% more expensive than in Germany to being 26% more expensive (Figure 25).

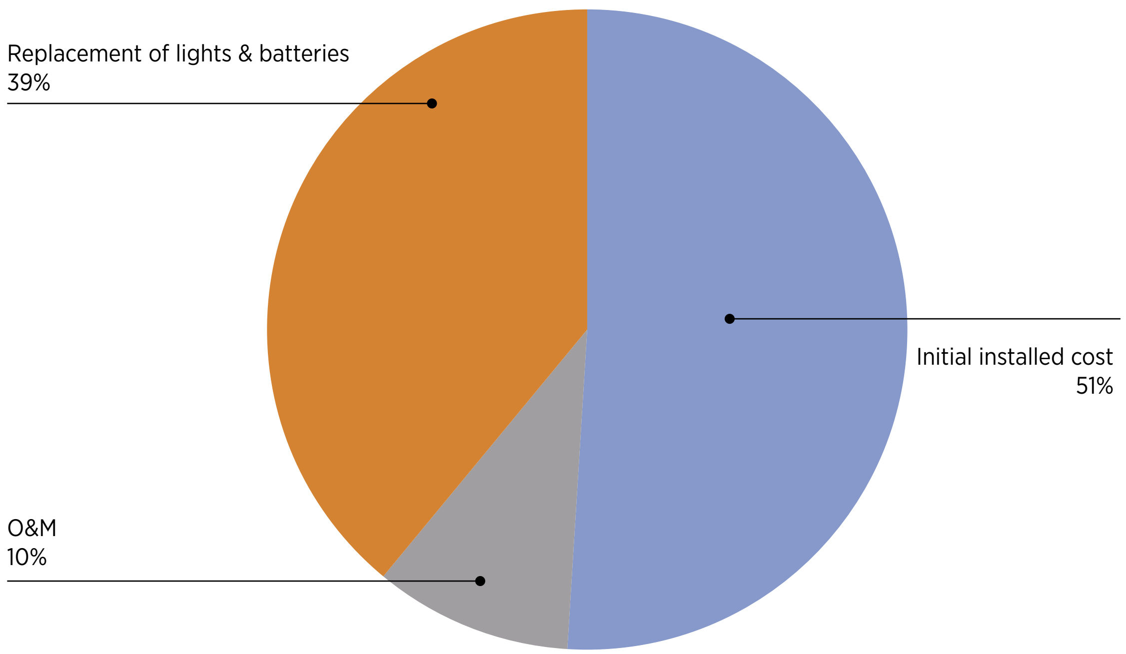
Small-scale distributed solar PV in South Africa represented around one-fifth of the market between 2013 and 2015, with around 170 MW of new rooftop capacity installed in 2015. The South African rooftop market is being driven purely by economics, as there are no major support policies in place. Current regulations are set at the municipal level, and given that municipal finances often rely on electricity distribution for a large share of their income, the municipalities themselves have little incentive to support increased residential PV installations (Retief, 2014).

The Moroccan government initiated the deployment of SHS as a solution for rural electrification in 1996. The country therefore was a pioneer in this application. This initiative, which also included grid extension, has provided more than 12 million people with access to the grid, and a total of 5 159 SHS have been deployed in the country (Morocco World News, 2015).

In Ghana, solar panels are free from import duty charges, but batteries, inverters and accessories are not, unless they are already packaged with the panels before they enter the country (pre-packaging is often unfeasible for larger-scale systems). The Renewable Energy Department at the Ghana Ministry of Energy presented that the cost of PV energy delivery for a 100 Wp solar home system providing three lighting points and a socket for radio/TV (about 300 Wh/day) has an initial capital cost of about USD 1 100. This number is therefore comparable to the ranges presented previously. The cost breakdown is shown in Figure 26.

Figure 26: Cost breakdown of 100 Wp solar PV system (above) and annualised life-cycle cost (below) in Ghana





Source: Ahiataku-Togobo, 2015

BOX 5

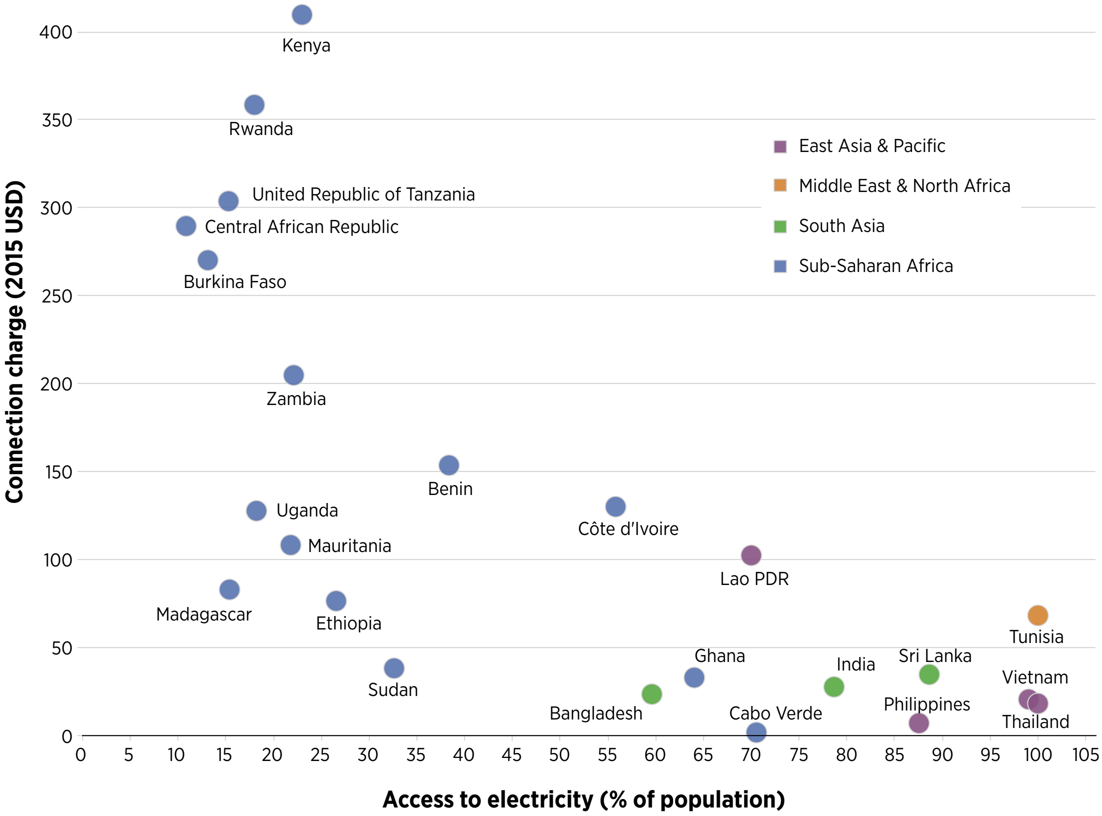
High grid-connection charges can make SHS attractive even in areas served by the grid

The current connection charges in sub-Saharan Africa are among the highest in the world relative to average incomes (World Bank, 2013), as Figure 27 shows. This graph displays the relation between connection charges and national electrification rates. As indicated in the figure, many African countries are in the top left quadrant of the graph, which means they have low electrification rates and at the same time have relatively high fees for the connection to the grid.

There are several ways that electricity companies can help to reduce these fees. They can lower their connection-related costs by adapting various low-cost technologies in their distribution networks. For this purpose adapting various renewable energy technologies will be a great help. Material bulk purchase, charge distribution over time, subsidising connections or amortising the cost of connection through loans can be the solution for lowering total connection fees (World Bank, 2013).

As one example, Kenya Power has initiated an effort to cut the cost of connecting rural homes to the grid through the Single Wire Earthing Return (SWER) system and the Last Mile Connectivity Project (LMCP). Kenya Power will use single, thinner and lighter cables instead of the existing systems with two or four cables to connect households to the nearest electricity poles. Through this cost reduction, they are planning to add a minimum of 284 000 residential homes and 30 000 commercial customers to the grid (Njoroge, 2015).

FIGURE 27: THE RELATIONSHIP BETWEEN CONNECTION CHARGES AND NATIONAL ELECTRIFICATION RATES



Source: World Bank, 2013

Cost reduction potentials for solar home systems in Africa

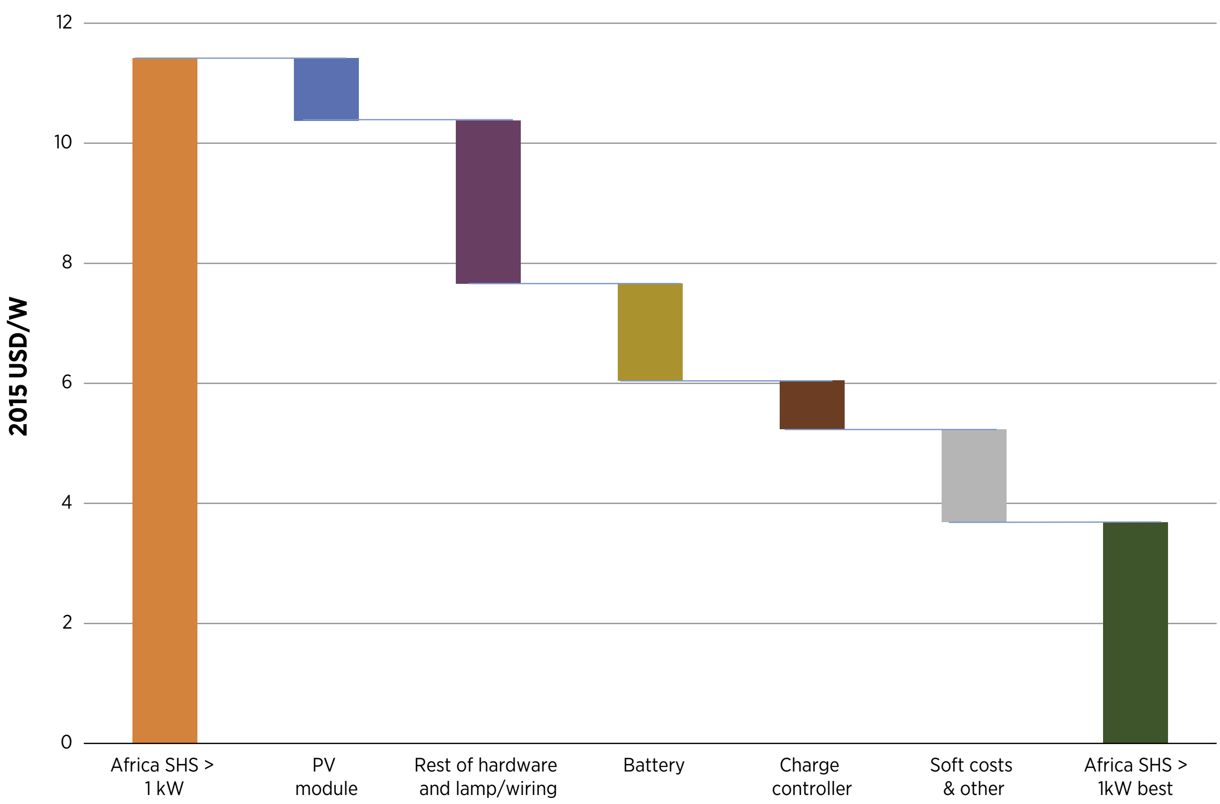
Although the costs of SHS systems have come down with declining costs in solar PV modules and many BoS components, there remains a wide differential between the most competitive cost structures for SHS and the average. These cost differentials, as well as the cost differentials compared to a much more established SHS market like Bangladesh, provide a starting point for examining what an "efficient" cost structure might look like for Africa.

Figure 28 shows a comparison between one of the higher-cost, larger than 1 kW SHS in the database with the best practice project in Africa for which IRENA has detailed data. This shows the potential sources of cost reduction if African SHS systems costs are moved rapidly to the local best practice. Overall, this comparison suggests that cost reductions of around 68% could be possible.

The average specific cost per watt of solar PV modules for Africa's best practice example are around half the average value experienced and account for 9% of the total reduction in installed costs. Reducing the balance of the hardware costs to African best practice levels would account for 24% of the reduction in total installed costs, battery costs would account for 14%, the charge controller for 7% and the soft costs for 14%.

This comparison needs to be treated with some caution, as it is not clear that the cost allocation has been applied rigorously in all cases. This is due predominantly to a poor understanding of the cost breakdown, but in some cases it undoubtedly reflects confusion about where to allocate costs at the more detailed level requested (Annex 1).

Figure 28: Average cost reduction potential of solar home systems (>1 kW) in Africa relative to the best in class, 2013-2014



Source: World Bank, 2013

In addition, given that there is a relatively poor understanding of the size and nature of individual markets in Africa, these two indicative costs examples cannot be used to identify the average cost reduction potential.

The reality is that a much more detailed engagement with stakeholders is required at a country and regional level to identify robust estimates of the size of different market segments by factors such as the country, the typical product being sold and the average cost of these products. This would need to be complemented by an analysis of the cost breakdown that goes beyond accepting data based on company classifications, but which verifies that these classifications have the same boundary conditions as requested and are consistent across data providers. The resources required to undertake this kind of detailed stakeholder engagement and analysis would be considerable and are beyond the scope of this project.

In addition to the analysis of today's cost reduction potentials relative to what might be a competitive cost structure for Africa today, it also is useful to analyse the additional cost reductions that will occur from continuing improvements in module technology, efficiency and cost reductions, as well as trends in battery costs.

With learning rates[18] of between 18% and 22% for solar PV, the accelerated deployment of solar PV results in a virtuous cycle of improving technology and falling costs; however, as cumulative installed capacity grows, the gigawatts required to double cumulative installed capacity also grow. Another important point is that in today's era of low PV module prices, the absolute cost reductions from modules are going to be relatively smaller for the same percentage reduction. Fortunately, as module efficiency increases, the area required for a given wattage declines, also helping to reduce BoS needs. IRENA's REmap analysis of the doubling of the share of renewable energy in the global energy mix by 2030 suggests that total installed solar PV capacity could reach between 1 700 and 2 500 GW by 2030.

18 The learning rate is the average percentage reduction in costs for every doubling of cumulative installed capacity of a technology.

Global average PV module prices could fall significantly to between USD 0.28 and USD 0.46/W by 2025 depending on the assumptions used and based on a top-down learning curve and bottom-up technology-based economic analysis (IRENA, 2016c). This highlights just how important it is to reduce all of the system component costs of solar PV systems, as the global average module cost may fall by just USD 0.25/W compared to 2015 by 2025. It also is critical to drive down costs towards today's best practice, as this represents the largest cost reduction potential by far.

Currently large shares of SHS in Africa rely on inexpensive lead-acid batteries and, for the more sophisticated systems, deep-cycle lead-acid batteries. But several small SHS suppliers started distributing high-quality lithium-ion (Li-ion) batteries, which have a longer battery life than lead-acid batteries and can operate at much higher depth of discharge rates with reducing battery lifetimes. Opportunity exists to reduce the costs of the mature lead-acid battery technologies in the future, but to a lesser extent than for Li-ion batteries.

With the recent rapid cost declines for Li-ion batteries and excellent prospects for future cost reductions, there may be a tipping point in the near future where it makes economic sense to use Li-ion batteries more widely for SHS and bigger-size PV systems in Africa. This will raise initial installed costs but will result in a lower LCOE over the life of the system and also extend significantly the time between battery replacements, helping to improve the probability that systems will remain active over their economic lifetime. There are some question marks over whether the current pay-as-you-go business models will act to accelerate or hinder the transition to Li-ion batteries. Companies in this market segment have an incentive to minimise upfront capital needs by using cheaper lead-acid batteries, but the potential for more attractive tariff rates for customers from the lower life-cycle costs of Li-ion batteries could push companies towards Li-ion batteries. Trends in battery storage choice merit closer monitoring, as well as ensuring SHS companies are aware of the economic benefits to customers of Li-ion batteries.

The development of batteries might be the most significant game changer in the price and capacity of SHS. The reduction in battery costs and the increase in quality is driven by the transfer of the research and development on rechargeable batteries for the consumer electronics market to the solar market. Because the price for solar panels is already relatively low, batteries are the major remaining bottleneck for affordable SHS that can power everything a household needs.

Solar PV mini-grid costs

Mini-grid solar PV systems can be divided into grid-connected mini-grid systems and off-grid systems. Such systems can be further divided into PV-hybrid systems (typically with diesel, but they also can include hydropower, biomass, wind, etc.), PV-hybrid systems with batteries and PV-only with a battery system. With the extensive use of diesel-based mini-grids (Box 6) there are opportunities to not only hybridise existing diesel mini-grids, but also develop new mini-grids with the decline in solar PV and Li-ion battery costs, incorporating solar PV has become highly economic to reduce diesel costs. The decline in battery costs means that higher levels of solar PV than have been applied previously are also now economic (IRENA, 2014).

Two other important distinctions for mini-grids are whether they distribute electricity in AC or DC and what size they are – which also is related to whether they distribute the electricity in single-phase or three-phase systems (nano/pico grids for single-phase and micro/mini-grids for three-phase). DC pico-grid systems are emerging as an intermediate step in the electrification process from SHS to mini-grids for users in Africa and South East Asia. DC pico grids connect together SHS so that they form a small grid to exchange electricity and storage capabilities. In these very small grid systems, DC grids can build on existing SHS investments, but the power usage is rather limited and only DC appliances can be used.

The sizes of mini-grid systems available for this analysis are between 5 kW and 1 MW, with the dataset containing information on 33 mini-grids in Africa. A total of 16 of these projects are mini-grids that are connected to the national grid, and the remainder are off-grid mini-grids. Those connected to the grid represent mini-grids that have generating or back-up power systems that allow the mini-grid to continue to function smoothly and to provide stable electricity supplies within accepted limits for voltage and frequency during periods of deteriorating power quality from the grid, or when blackouts occur on the grid. They can be at educational facilities, mining operations, hospitals, other government facilities, etc.

In Africa, countries such as Egypt, Kenya, Mali, Senegal and Tanzania have installed solar PV-based mini-grid systems, although numbers are still modest relative to demand. Tanzania has just started to accelerate the deployment of mini-grid systems with the help of financing from the African Development Bank. Aside from the AfDB, several other development partners including the World Bank, the Swedish International Development Cooperation Agency (SIDA), the IFC and GIZ have a longer history in promoting mini-grids in Africa. Outside of Africa, India has installed hundreds of PV mini-grids and Indonesia and Bangladesh are in the process of accelerating the deployment of PV mini-grids as a solution for rural electrification as the next step from SHS.

Figure 29 shows the total installed costs of mini-grids by system size. Compared to the cost distribution of SHS, the cost gap between similar-size systems is narrower, but again with relatively few data points. The off-grid systems under 125 kW have the largest cost variation, while the cost variance declines as system sizes increase. There exists the regional costs differences, with PV mini-grids in North Africa and East Africa appearing to have the lowest costs. The systems in West Africa for which IRENA has data are smaller in size, with correspondingly higher costs per watt, although the larger systems are close to the median value of USD 2.9/W (with little difference for the on- and off-grid projects). The average values are higher than the median for off-grid systems, and are only slightly higher than the median for on-grid systems.

Figure 29: PV mini-grid system costs by system size in Africa, 2011-2015

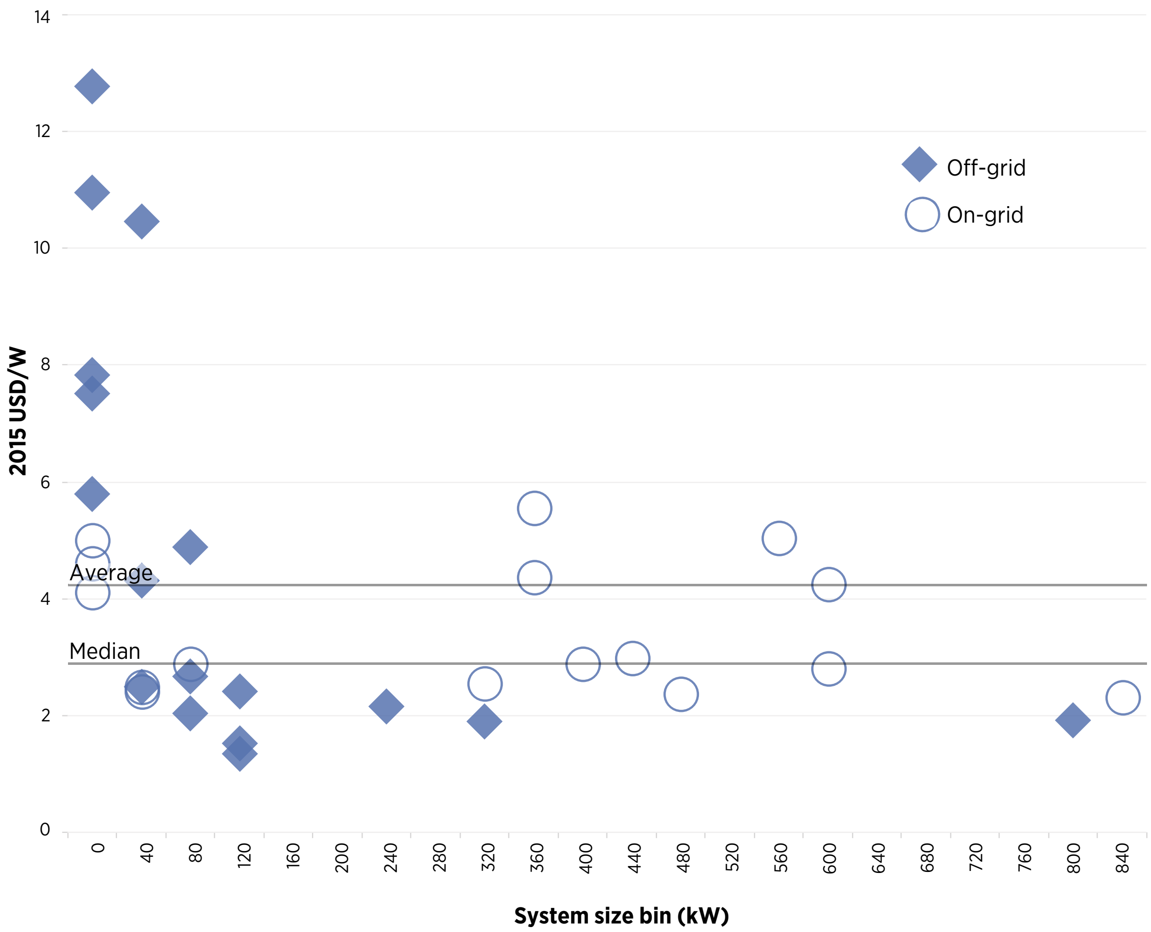


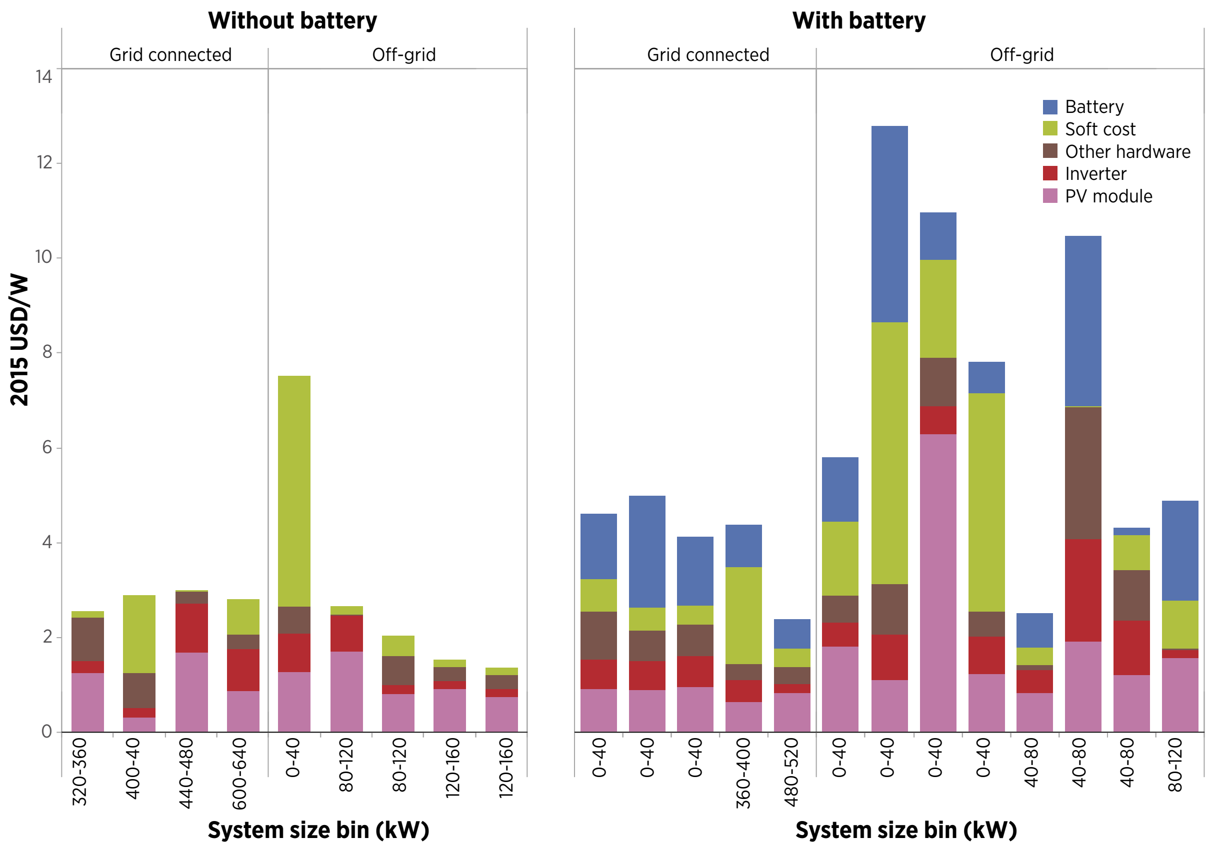
Figure 30 shows the cost breakdown where the data are available. The first four projects are grid-connected mini-grids without batteries that were commissioned between 2011 and 2014. These systems can operate independently in case of a grid blackout. These systems are larger than off-grid systems, given that they are in most cases solar PV additions to existing mini-grids where economic activity is already present and are supporting the existing mini-grid, making the economic case for large-solar PV integration from diesel savings compelling. The total installed costs of these projects range between USD 2.5 and USD 3/W and benefit from their relative scale in order to help keep costs low. The inverter costs in some of these systems are higher than what might be expected for systems of this size using standard inverters; this may be due to the use of micro-inverters for their additional flexibility or could simply reflect higher cost structures in Africa.[19]

19 Micro-inverters currently cost around three times more than central or string inverters (IRENA, 2016b).

The next five projects are off-grid mini-grid projects without battery systems, sometimes also called "fuel saver" systems as they are often scaled to maximise the solar PV fraction of demand, without the use of batteries, in order to reduce diesel costs. The smaller-scale system has a high cost structure, but the larger, more recently installed systems have very competitive costs, as low as USD 1.4/W. The solar PV modules for these systems were reported as costing between USD 0.7 and USD 1.7/W, and soft costs were low at between USD 0.1 and USD 0.4/W for four of the projects, with the smallest project having significantly higher soft costs at USD 4.9/W.

The grid-connected mini-grids with battery storage exhibit higher installed costs, in the range of USD 2.4 to USD 5/W. They have battery costs of between USD 0.6 and USD 2.4/W depending on the size of the battery, scale of project and location. Solar PV module prices for these systems vary from a competitive USD 0.6/W to a high

Figure 30: Solar PV mini-grid total installed cost and breakdown by cost component, 2011-2015



Note: All system sizes have been rounded.

of around USD 0.9/W. Inverter costs vary from a low of USD 0.2/W to a high of USD 0.65/W. Other hardware costs vary between USD 0.35/W and USD 1/W. The soft costs for these projects are between USD 0.4 and USD 0.7/W for four of the projects, with one project having significantly higher soft costs of USD 2/W.

Off-grid mini-grid projects including batteries show a larger variation in total costs, particularly due to the variation in battery costs, module costs and soft costs. This represents the very significant differences in the potential location of these systems (close to a port and infrastructure, or far inland in remote areas) as well as system configuration. The small sample size also plays a role, given this inherent variability. Solar PV module costs for these systems were between USD 0.8 and USD 2.8/W for seven of the projects, but USD 6.3/W for one project. Inverter costs ranged from a low of USD 0.163/W, which is very close to utility-scale costs for string or central inverters, and a high of USD 2.2/W. Other hardware costs ranged from a low of USD 0.1/W to USD 2.8/W where reported, with soft costs from a competitive USD 0.4/W to a high of USD 5.5/W for the very small system. Battery costs varied widely, depending on the size of the battery and the project, from a low of USD 0.1/W to USD 4.1/W for the most expensive.

For mini-grids without batteries, solar PV modules account for 11-64% of total installed costs, and the simple average is around 44% (Figure 32). Inverters and other hardware costs both share the same ranges and average, at 7-35% of total installed costs, with an average of 18%. Soft costs (where reported) account for 5-65% of total installed costs, with an average of 22%.

For mini-grids with batteries, the solar PV modules account for 7-57% of total installed costs, with an average of 26%, which is 18 percentage points lower than for mini-grids without batteries. Inverters account for an average of 13%, with a range of 3-27%, other hardware for an average of 13% with a range of 1-27%, and soft costs for an average of

BOX 6

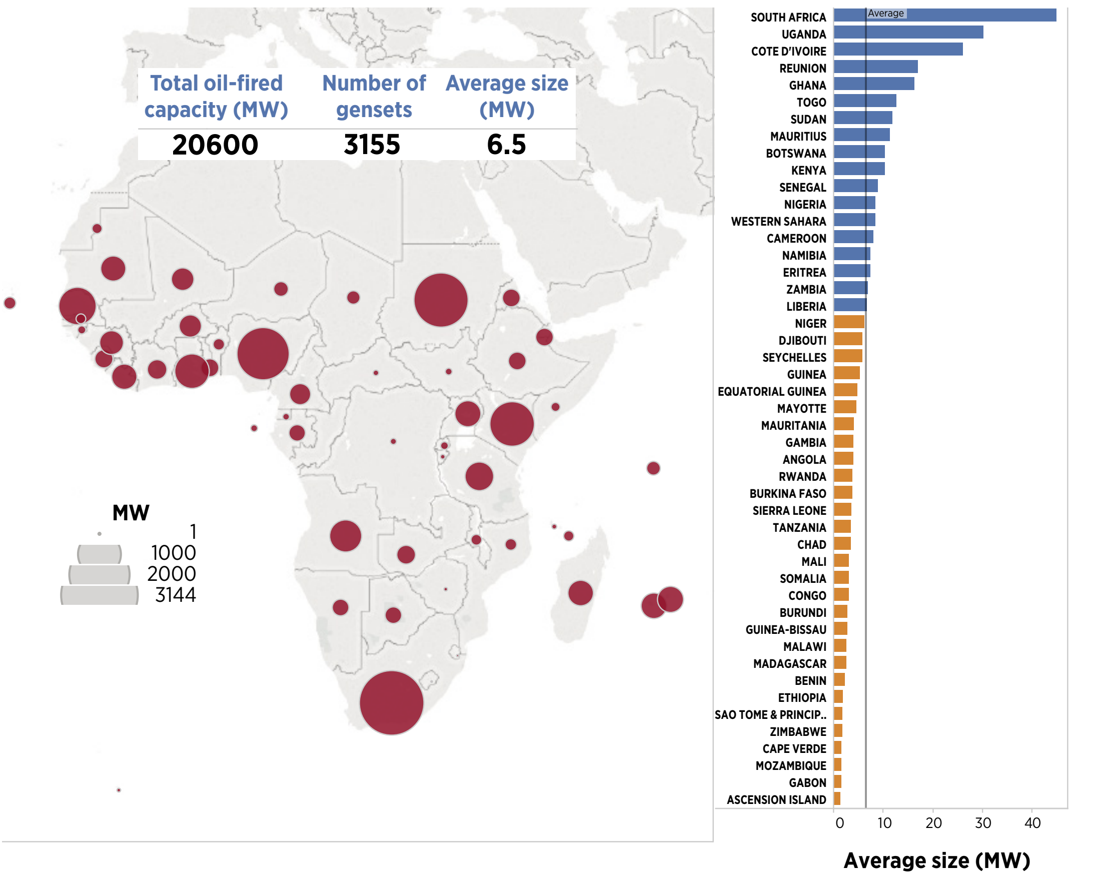
Existing diesel-based mini-grids

The extensive use of diesel to supply electricity in mini-grids in areas not connected to the national grid represents a very large economic opportunity for solar PV. By creating a hybrid mini-grid by "solarising" existing diesel-based mini-grids and by replacing the existing diesel-fired back-up generators of grid-connected customers, diesel costs can be reduced greatly.

The addition of solar PV to existing diesel mini-grids is an increasingly economic option. Africa as a whole has around 35 GW of oil-fired generation capacity, and sub-Saharan Africa has around 19.7 GW (Platts, 2015). South Africa, Sudan, Kenya, Nigeria and Senegal all have significant oil-fired capacity (Figure 31). Yet the average size of these utility-scale oil-fired units is only around 6.3 MW each.

Taking into account the utility-scale generators and small-scale units, the total market size for diesel generators in Africa has varied between 1.3 GW and 1.7 GW per year. Solar PV can help displace this demand and reduce the actual generation of diesel-fired plants in Africa through a combination of utility-scale deployment, solar PV mini-grids (with or without storage) and SHS. Several countries have made progress in deploying mini-grids as a solution for rural electrification instead of grid extension. Kenya, Mali, Namibia, Senegal and Tanzania all have become aware of this Potential (EUEI PDF and GIZ, 2014). Yet there remains huge untapped potential to reduce diesel consumption through the more widespread use of solar PV in existing mini-grids.

Figure 31: Existing oil/diesel generator capacity in sub-Saharan Africa and average size per generator



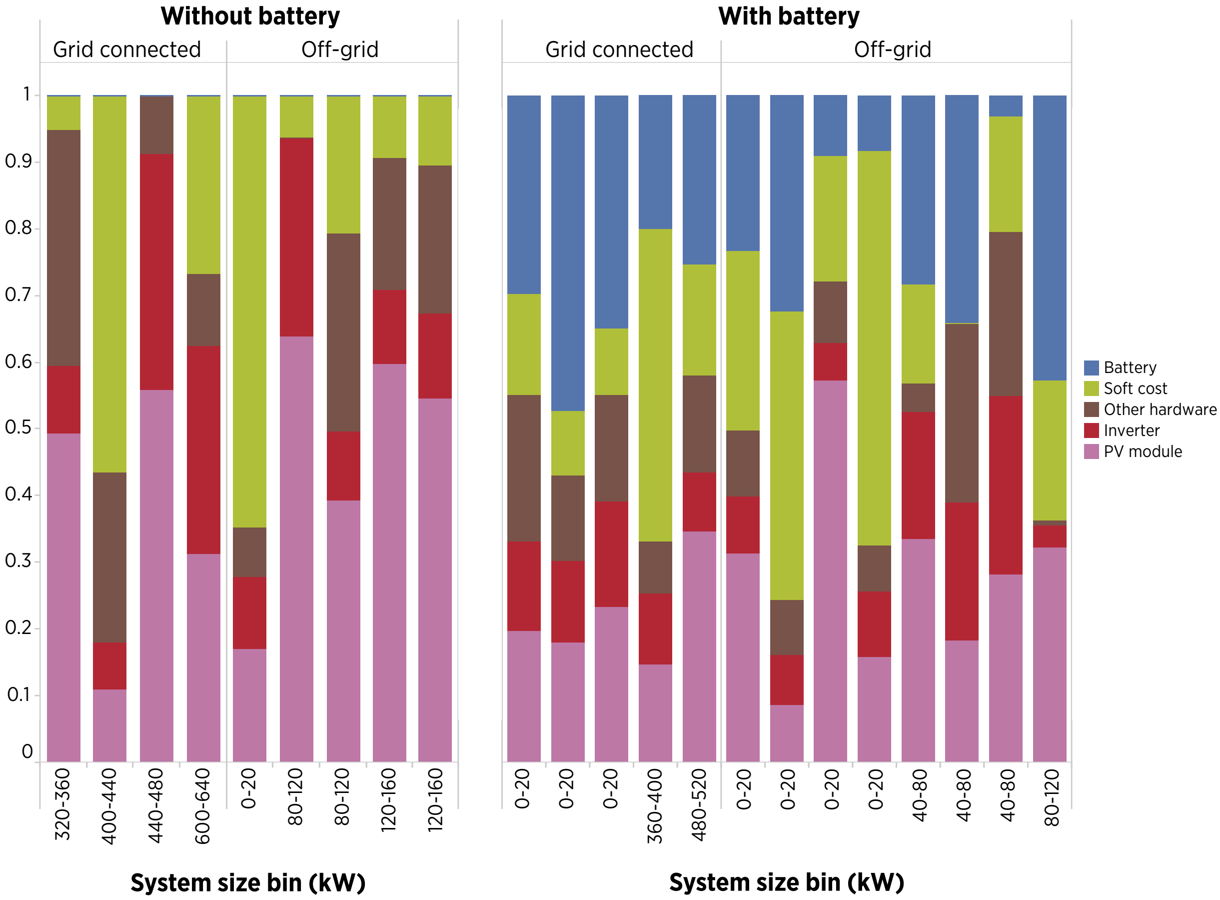
Source: Platts, 2016

Table 6: Diesel generator sales in Africa, 2011-2014

Year	2011	2012	2013	2014
Total amount (GW)	1.3	1.2	1.2	1.7

Source: Haight, 2012, 2013, 2014, and 2015.

Figure 32: Solar PV mini-grid share of cost components in total installed costs, 2011-2015



Note: All system sizes have been rounded.

23% with a range of 10-59%. The average share of batteries will be determined not only by the cost per kWh of storage, but also by the amount of storage that is integrated into the mini-grid system. The share of these two components varies from a low of 3% to a high of 47%, with an average of 26% for the systems for which IRENA has data.

The use of batteries in PV-diesel hybrid systems is not simply about the provision of electricity outside of daylight hours. The battery storage can play an important role in ensuring that the mini-grid system can operate stably, as it can immediately act to inject power if clouds pass over the PV array, thereby replacing the need for spinning reserve. This is important because small-scale solar PV systems are more vulnerable to passing clouds. Single arrays lack the geographic distribution of a larger numbers of arrays in different locations, which means that cloud effects are smoothed-out, reducing variability. With the right sizing of the solar PV array and battery system, the storage system therefore can ensure that diesel generators can be shut down during peak solar hours, reducing or eliminating the need for the generators to operate at inefficient load levels in order to be available to maintain grid stability. By avoiding part-load operation of the diesel gensets, diesel consumption is reduced, as part-load operation reduces efficiency and results in higher diesel consumption. This also reduces wear and tear on the diesel generators, reducing maintenance costs and extending their operational lifetimes.

All these points result in a maximisation of the diesel fuel savings of hybrid systems, as the battery system ensures that the diesel generators are operating only when they are needed and that they run at their most efficient level. This type of integration of solar PV-diesel hybrid systems with battery storage necessitates a more complex system design and operational strategy, but is more cost-effective (HOMER Webinar, 2015).

BOX 7: Emerging and niche applications of solar PV in Africa

In addition to providing electricity access to off-grid households and villages, there are a range of applications for solar PV to promote productive activities. These include products especially designed for small applications – including machines for juice pressing, grinding, cooling and many others – all powered by solar PV. Below are a few of the more significant applications in Africa, although it is not an exhaustive list.

PV for mining

African countries' biggest electricity consumption comes from the industrial sector, and the mining industry accounts for the largest share of this. For mining companies, the biggest cost components are typically labour and energy, which account for 15% to 20% of the total costs. When PV is added on to existing diesel generators, it reduces diesel consumption during the daytime. As a result, mining companies can expect 25% to 30% reductions in diesel costs, with more if combined with energy storage to increase the solar fraction (THEnergy and CRONIMET , 2015). Currently, mines can enter into PPAs for solar PV-diesel hybrid solutions with an IPP which, depending on the local circumstances, can offer a discount of 20-50% compared to a straight diesel only mini-grid (Judd, 2014). There are several such projects existing in South Africa and Australia.

Solar PV food dryer

One creative application is the use of solar PV modules with thermal collectors to power a solar dryer for the forced circulation of air for the dehydration of fruits and vegetables and also for cleaning threshed agricultural products. The storage of food is a crucial matter in countries lacking access to electricity, since many fresh products, which cannot be refrigerated, have a greatly reduced shelf life. A small solar dryer can solve this problem and even generate additional income to small farmers, since dried fruits and vegetables can be stored for months. In these so-called active solar dryers, the solar PV system powers small fans, which accelerate air circulation and create a system which is much more efficient than passive solar drying or even simple sun drying. Experiences with these simple systems have been gathered in countries such as Zimbabwe, India and many others. (Weisse and Buchinger, 2008)

Solar PV telecom tower

Another fitting application for solar PV technology is the powering of telecommunication stations. More than 700 million people in Africa have access to mobile phones, and the market is the fastest growing worldwide. To provide network coverage even to remote locations, the installation of telecom stations has grown in recent years. In 2014, 145 100 telecom towers were off-grid and a further 84 300 were in areas with unreliable supply, necessitating back-up (IFC, GSMA and GPM, 2014). With a predictable and stable load profile, a solar PV system to power a telecom tower 24 hours a day year-round can be designed easily. Solar PV can reduce diesel costs and the risk of logistical problems, ensuring power supply for the station for over 20 years without the necessity of transporting fuel to the site, and with very low operation and maintenance costs. Such systems can be monitored remotely and can be expanded easily if the load requirements increase, or the systems can be oversized to provide electricity to local communities (Phaesun, 2011).

Solar irrigation pump

In remote areas with no access to an above-ground water source or in dry climates, a solar PV system can be installed to provide irrigation for small farmers. The system is generally designed with a water tank above ground so that whenever the sun is shining, water is pumped into the water storage tank to be used later for irrigation of the farm. Such a system does not require a battery, reducing total system costs significantly. Another necessary part for an irrigation system is a constant current pump. Solar PV irrigation systems have already been used quite extensively in North Africa, especially in Egypt, and can be implemented in many other regions of the continent. The solar PV solution can easily be scaled to address the area to be irrigated (Schumacher Centre, 2010).

BOX 8

Innovative business model examples of solar PV in Africa

SunEdison (solar pumps and micro power station)

SunEdison deals with several different solar PV system categories: solar pumping, solar-powered micro stations for rural telecom, and village electrification. The company announced plans to bring electricity to 20 million people by 2020, with the goal of lighting up 1 million homes in 2015.

The point of difference for SunEdison's approach is that most of their projects involve new financing methods, each of which is tailored for the communities which will use the system. SunEdison partners with certain foundations and is aiming to electrify 100 remote villages in a year. They also are partnering with a company which builds micro power stations for rural telecom towers and villages. An important point of this business model is that by "having a telecom as the anchor customer for the project, they can finance the project using a hybrid power purchase agreement even though villagers have little or no credit".

SunEdison also provides a micro station, which is a solar panel on top of a cabinet that houses a battery and power components. Depending on the requirements, this can be multiplied as a modular solution (Tweed, 2015).

M-KOPA/ M-PESA (pay-as-you-go SHS in Kenya, Tanzania and Ghana)

M-KOPA indicates that off-grid households in East Africa, which also are largely low-income households, spend about USD 0.50 to USD 0.60 per day on kerosene lighting and basic charging costs for torches or batteries. The company can, on the other hand, provide a SHS for USD 0.45 per day with their "pay-as-you-go" systems for off-grid households in Kenya, Uganda and Tanzania (Jackson, 2015). Together with pre-paid systems this shows that innovative market models can result in successful deployment of solar PV technology in low-income regions, while still being sustainable for the system providers.

M-KOPA was launched in October 2012 and since has connected nearly 300 000 homes in the East African countries of Kenya, Tanzania and Uganda to solar power. Currently, 500 new homes are connected every day. The reason for this success lies in the fact that by using a pay-per-use mobile plan, M-KOPA was able to make SHS affordable to low-income households. Such mobile payments are collected in real-time by systems such as M-PESA in Kenya, which are now the preferred banking solution in many parts of rural Africa. The company recently has started to license its technology to partners in other African markets, initially in Ghana with PEG Ghana Solar (M-KOPA SOLAR, 2015).

Azuri (pay-as-you-go model for SHS in Tanzania and Ghana)

Another company which has had success in Africa with a pay-as-you-go business model is UK-based Azuri Technologies. Currently focusing on the Tanzanian market, they partner with the telecom provider Tigo and the retailer Lotus Africa. With this co-operation, the company aims to supply 100 000 rural houses with state-of-the-art SHS by 2018. The pay-as-you-go system is provided by Tigo Pesa, and Lotus Africa will serve as a point-of-sale, delivery and service point for the Azuri product. Several sizes of SHS are available, as well as services for larger and richer households. All packages include a mobile phone and a SIM card that is used for the mobile payments for the small amounts of electricity, even weeks in advance. In case of no payment, Azuri can turn off the system remotely (Gifford, 2015).

Solar kiosk (fee-for-service model)

Solar kiosks range in size from 1 to 4 kW and can be scaled up to any size. These kiosks offer services starting from mobile phone charging, up to cooling of medicines and charging of solar lamps and several additional services that are necessary for rural populations in African villages. So far these kiosks are located in Kenya, Ethiopia, Tanzania, Botswana, Rwanda and Ghana where the subsidiary company operates and manages the systems. In Nigeria and Vietnam, there is one single pilot kiosk, which is managed by the local partner. The total number of kiosks installed was expected to reach 150 by the end of 2015. The German-based company producing the kiosks currently has projects with the ACP-EU Energy Facility in three countries: Ethiopia, Kenya and Madagascar.

Their revenue comes from various sources:

1) Provision of services (mobile phone charging, faxing/copying, cooling drinks, Internet access, TV viewing)

2) Sales of products: SHS (Fosera Scandle), cooking stoves, farming solutions, fertilisers, FMCG rice, flour, toiletries, etc.

3) The usage of the kiosk as a solution for telecom and mini-grids.

The US beverage company Coca-Cola also has started supplying solar kiosks to rural areas of Africa with its so-called Ekocenter. This solar kiosk is providing not only electricity to people, but also water tanks with purified drinking water. In addition, a refrigerator for vaccines is included in the containerised PV system. Coca-Cola's has announced plans to supply 1 500 to 2 000 Ekocenters to around 20 countries by 2015 (Designboom, 2013).

Utility-scale solar PV costs

Globally, utility-scale solar PV has dominated deployment in terms of MW installed. These systems, with an installed capacity of over 1 MW, offer important economies of scale over smaller rooftop or small mini-grid systems and are typically, but not always, grid-connected. Utility-scale projects show just how competitive solar PV can be. In the 2015 tender in Dubai for 100 MW, the winning bid was so low that Dubai Electricity and Water negotiated a doubling of the capacity to 200 MW at a PPA price of just USD 0.0584/kWh, slightly lower than the original offer. In 2016, this record was broken when the tender for 800 MW of capacity to be online in 2018 resulted in a record-low bid of USD 0.03/kWh. This is cheaper than fossil fuel equivalents, despite the United Arab Emirates being in the heart of the fossil fuel-rich Persian Gulf region. Tenders in 2016 in Mexico (USD 0.045/kWh) and Zambia (USD 0.06/kWh) have shown that where the right regulatory and policy frameworks are in place and access to low-cost finance is available, solar PV can compete on an equal footing with fossil fuels in the Sunbelt.

In 2015 and 2016 governments, utilities and investors have realised that low-cost utility-scale solar PV can compete with incumbent technologies in a wide range of circumstances. Solar PV costs will continue to fall (IRENA, 2016c), and this trend is not an exception anymore, but is increasingly the norm.

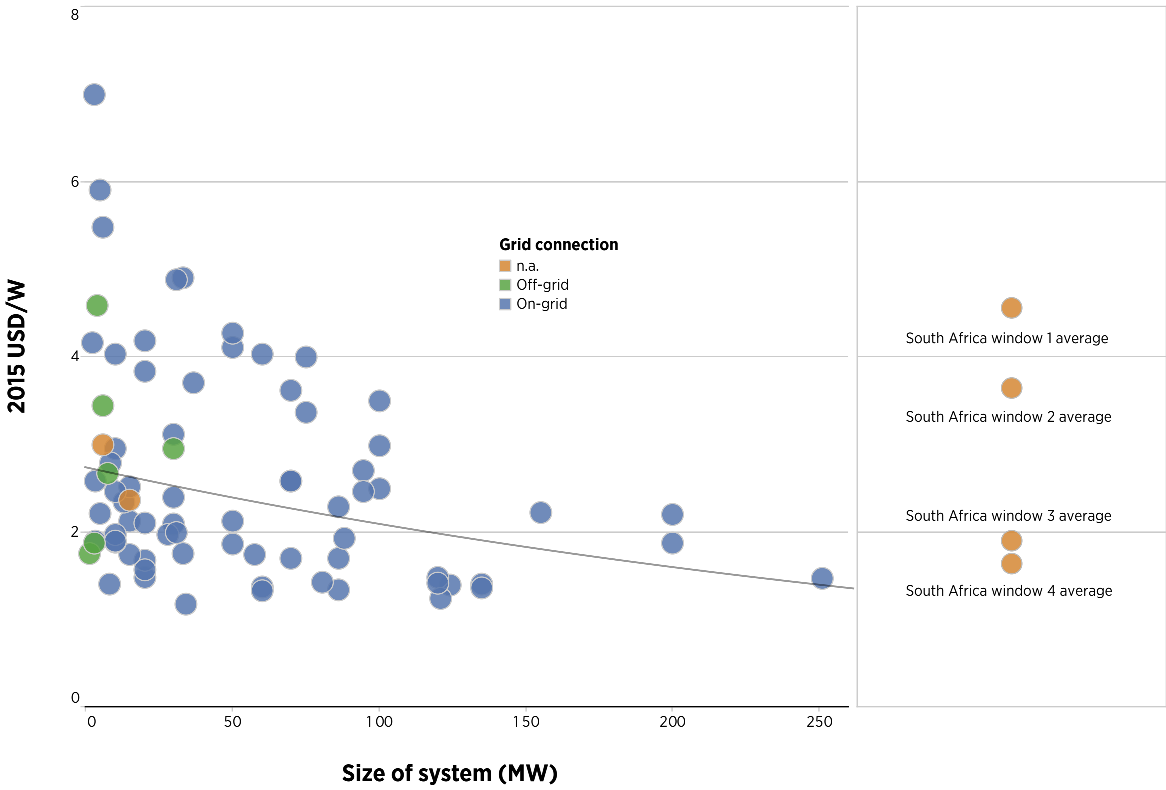
Africa, like most of the Sunbelt, is only just waking up to this huge economic opportunity. Outside of South Africa, there are relatively few operating solar PV power plants at the utility-scale, and most of these are relatively small (typically <30 MW) compared to many of the large projects seen in the rest of the world. The main driver on the continent since 2011 has been South Africa, due to the government's roll-out of MW-scale PV projects through the REIPPPP.

Confidentiality issues are extremely difficult to overcome in such a small market, where projects are easily identifiable. As a result, IRENA was unable to obtain data from developers on the cost breakdown of total installed costs; hence only total installed cost data are available. However, some data are available from secondary sources. These data can be compared to cost structures in other markets to help shed some light on the cost structure of utility-scale solar PV projects in Africa, although there is no guarantee that such a small dataset is representative of the very different cost dynamics in the very diverse countries that make up Africa.

Figure 33 shows the distribution of total project costs compared to the size of projects and whether they are grid-connected, or a project that encompasses a mix of solutions. For comparison, the average installed cost estimates for the South African REIPPPP windows also have been included. All of the 100 MW and greater projects on this chart represent a series of planned projects and the average installed cost for all of these proposed projects. It would be expected that the earlier stages of these projects would have a higher average cost than the final stage, but no data on this are available.

The simple average total installed cost of these projects over the period 2010 to 2017 is expected to be around USD 2.8/W, with a range from USD 7/W for a 2.5 MW project to around USD 1.2

Figure 33: Total project cost of operating and proposed utility-scale PV projects in Africa, 2010-2018



Source: Renewable Cost Database, 2016

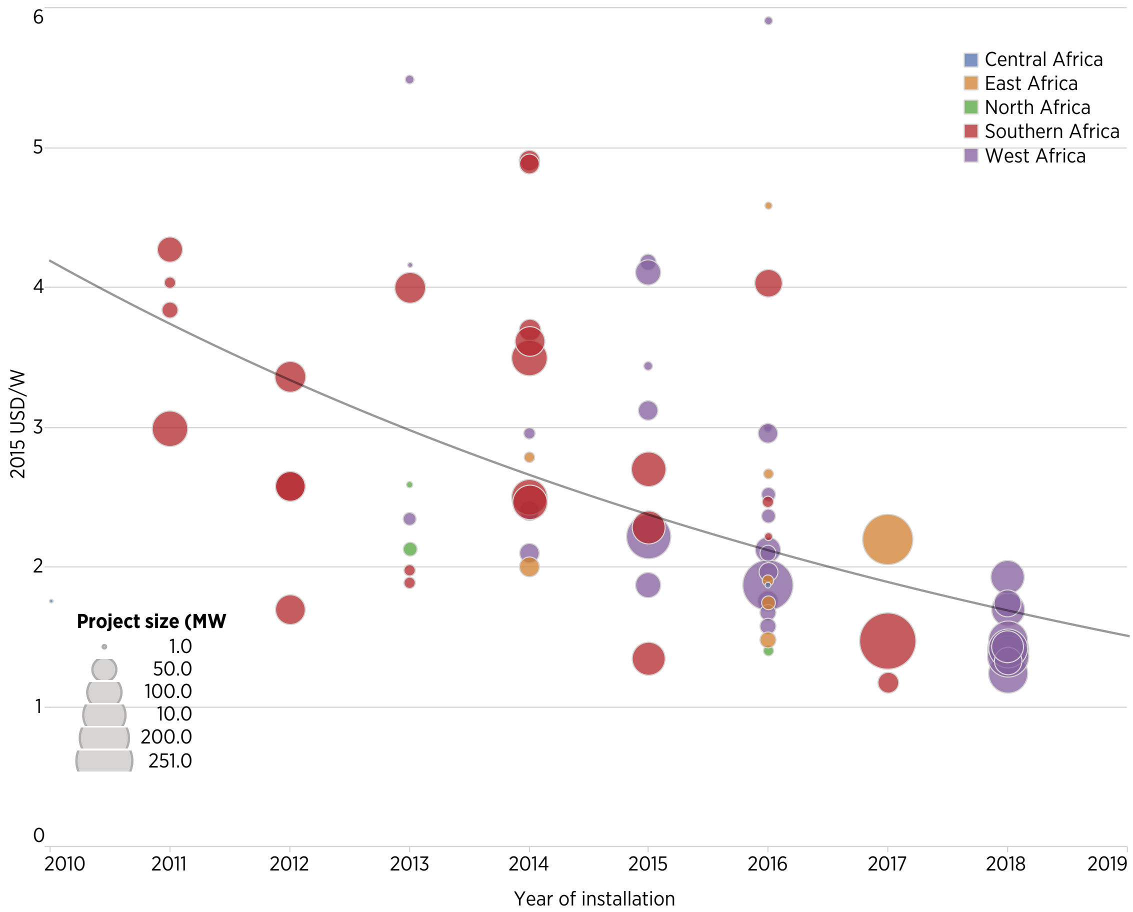
to USD 1.4/W at the lower end for both small (<40 MW) and large projects (80-100 MW). Similar to the experience with SHS and in other regions, the variation in installed costs is more pronounced at smaller project sizes, noticeably for projects up to 20 MW. However, given the small number of projects above 50 MW, this may be due simply to fewer data points. This will become clear only once the African market accelerates, but expectations are that economies of scale will allow the pattern suggested by the existing data to hold true (as is the case in other markets).

With the continued decline in solar PV installed costs, it is much more important to examine the total installed cost trend through time. Figure 34 presents the installed project costs by year of installation, project size and region for projects that are currently operating, under construction or proposed. With just a handful of projects between 2011 and 2013, costs for projects varied, with some very competitive projects and others that were more expensive (greater than USD 4/W). The period 2014 to 2018 shows a downward trend in installed costs, although the range remains quite large.

What is particularly encouraging is that a number of projects are targeting total installed costs of USD 2/W or less, with competitive projects at around USD 1.4/W. The latest auction for Zambia suggests that the Enel Green Power S.p.A bid is targeting total installed costs of around USD 1.2/W.[20] In the wider African context, it also appears that there will be a broadening of the more competitive projects beyond southern Africa, where strong civil engineering sectors exist and existing infrastructure is well established. Project developers are now targeting sub-USD 2/W cost ranges in East and West Africa. This suggests that with the right regulatory framework and access to finance, competitive cost structures for utility-scale solar PV are achievable throughout Africa. The key uncertainties are whether these projects actually will reach financial close and if these *ex-ante* cost estimates can be achieved.

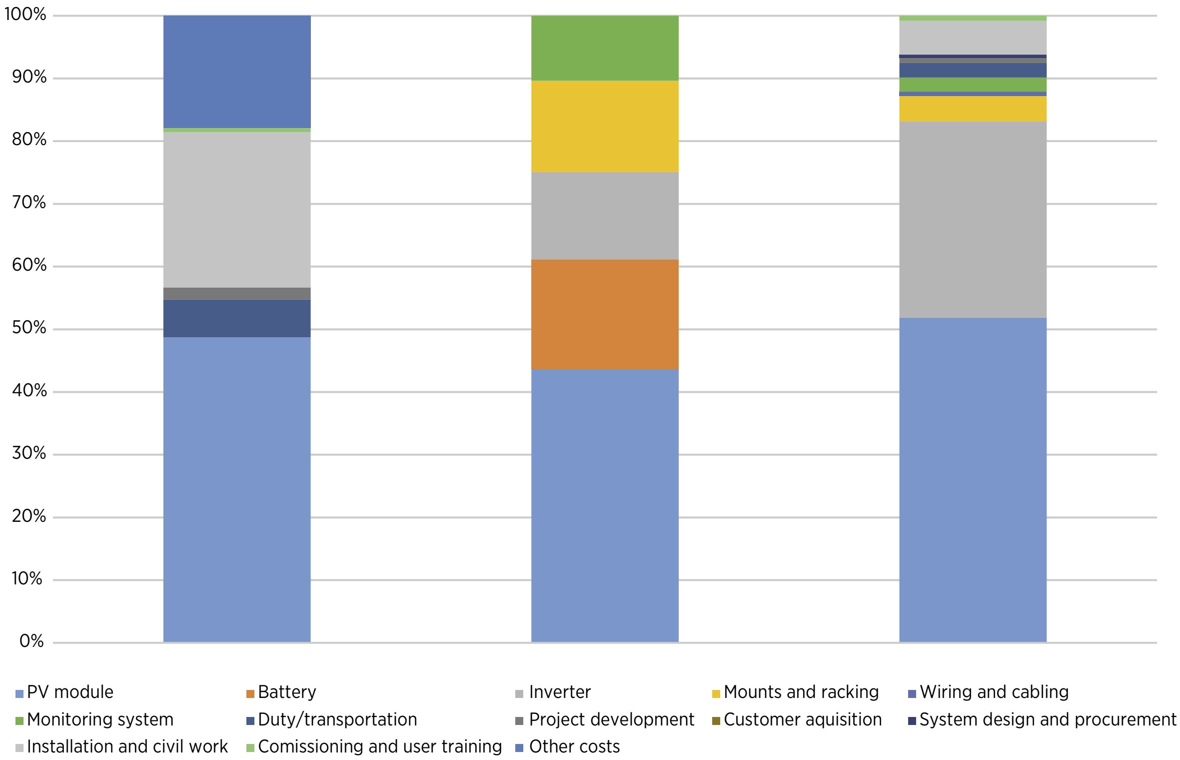
20 *See* Enel Green Power (2016).

Figure 34: Utility-scale total installed costs by project size and region for installation, 2011-2018



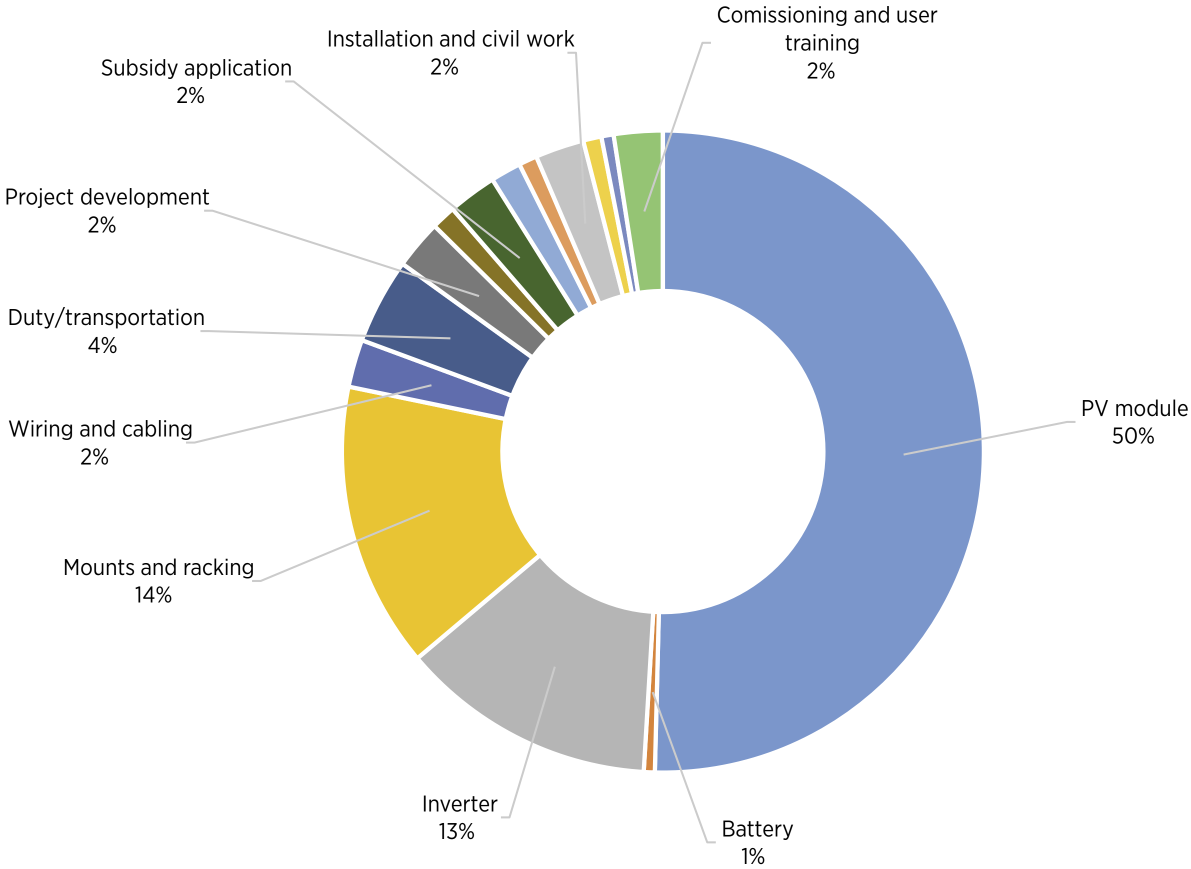
Source: IRENA Renewable Cost Database, 2016

Figure 35: Installed cost breakdown for three utility-scale PV projects, 2011 to 2016



Source: Renewable Cost Database, 2016

Figure 36: Detailed cost breakdown for a proposed utility-scale PV project in Africa



Source: IRENA Data and Statistics, 2015

Note: Excludes labels for shares of less than 2% of total costs except battery.

Given that a number of projects proposed for completion in 2016 appear unlikely to come online this year, 2017 should see a range of projects built with costs in the USD 1.2 to USD 2/W range. With the success of the recent tenders in Dubai, Mexico, Peru and Zambia and the urgent need for new capacity in sub-Saharan Africa, it is probable that there will be an acceleration of plans to deploy solar PV in the coming years given the solid economic case for solar PV. Countries where existing initiatives and regulatory frameworks are already in place or are in the process of being implemented – such as Egypt, Madagascar, Morocco, Nigeria, Senegal, South Africa and Tunisia – could be the early beneficiaries of the increased competition by international developers to expand into new markets.

Figure 35 presents the cost breakdowns for the projects for which information was available. Given that this is a very small sample, care needs to be taken in interpreting the results. Projects one and three are on-grid, while project two is off-grid. Project two is a new mini-grid system integrating a large battery to reduce diesel consumption from the outset. The share of PV modules in all three projects ranged between 44% and 52%, which is not widely different from the most competitive cost structures experienced globally, except in the case of project two due to the sizeable battery costs. The on-grid projects have a proportionately large share of the costs from the civil engineering works and installation.

Examining a separate project which has the most detailed cost breakdown highlights the fact that the development of local supply chains will have an important impact on bringing down costs (Figure 36). The share of racking and mounting in this project is 14%, well above what would be expected in a competitive cost structure where a share of 8% or less might be expected.

BOX 9

PV module efficiency and temperature relation

Elevated ambient temperatures lead to elevated solar cell temperatures. Due to the dark surface of a solar cell, the ambient temperature is amplified by solar radiation, generating in some cases cell temperatures well over 50 °C. The cell temperature has a direct impact on the open-circuit voltage and the short-circuit current. While short-circuit current increases slightly with rising temperature, open-circuit voltage is negatively impacted by a temperature increase. This leads to a lower maximal power point for the cell/module and results in a lower output power. The cell temperature is dependent not only on the ambient temperature and irradiation, but also on the mounting structure of the module (freestanding ground-mounted systems have better air circulation than rooftop-mounted modules) and also on the wind speed, which can cool down the cell surface. It therefore is very complex to estimate the cell temperature without very precise data on the system location and installation.

A study shows that even in Europe, a cell temperature around 20 °C higher than the ambient temperature can lead to around a 10% lower yield, depending on the mounting structure (Nordmann and Clavadetscher, 2003). Other studies compared the relative efficiency of modules in selected sites in Europe and areas with higher irradiation and ambient temperatures such as Tunisia and Cyprus. It was found that the relative efficiency decreases to around 85% in northern Africa in comparison to 92-93% in Scandinavia, due to increased cell temperatures. Nevertheless, due to the high irradiation in these hot countries the absolute efficiency is still better than in countries with low irradiation (Makrides *et al.*, 2010 and Huld *et al.*, 2010).

As a further example, a study in Saudi Arabia showed that the solar PV module resulted in 10.3% losses in efficiency due to a module temperature increase from 38 °C to 48 °C (Adjnoyi and Said, 2013). A temperature increase in this range over the whole year therefore would lead to energy yield loss of around 10%. Since the module temperature is dependent on so many factors, it is difficult to estimate exactly the effect of air temperature on the cell temperature and therefore on the energy output of the module. The temperature effect also is dependent on the module technology, due to structural differences in different cell technologies, especially with regard to thin-film solar PV.

The temperature impact on the maximal output power of a PV module can be calculated with a power temperature coefficient, which generally is available on the data sheets of PV modules. Whereas crystalline silicon modules have temperature coefficients of around -0.4%/°C, thin-film modules generally show a lower absolute temperature coefficient and therefore are less temperature-dependent. In thin-film technologies such as cadmium telluride or CIGS modules, this coefficient can vary from -0.25% to -0.1%/°C . This means that an increase of 25 °C in the cell temperature would lead to a performance loss of around 5% in thin-film modules, while a performance loss of around 10% could be expected for the crystalline silicon module under the same conditions (Virtuani *et al.*, 2010). Therefore with an increase of the air temperature, the same effect can be observed since the cell and ambient temperature are directly correlated.

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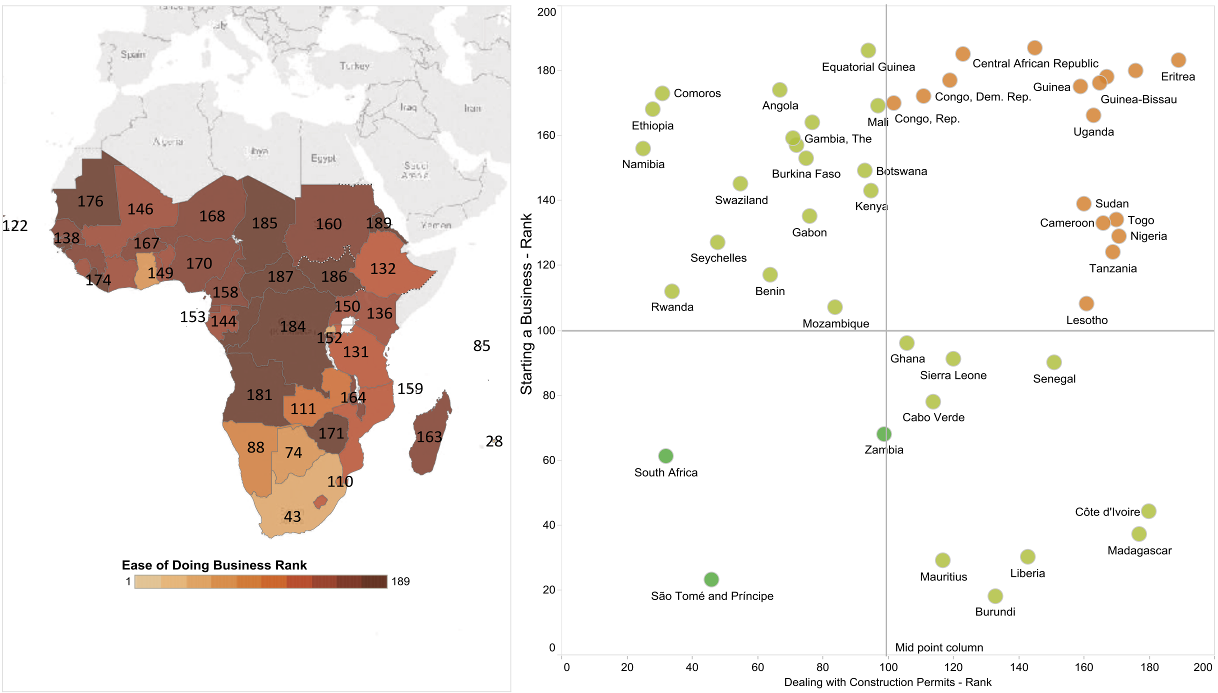
ANNEX 1: AFRICA'S CHALLENGING BUSINESS ENVIRONMENT

Africa's generally challenging business environment presents barriers to investment in the energy infrastructure required to fuel economic growth, expand electrification rates and meet development goals. Even where the policy and regulatory framework are in principle supportive of these goals, the magnitude of the barriers to doing business effectively and in a timely manner has meant that progress has been slower than would be ideal. Only three sub-Saharan Africa countries are ranked within the top 50 countries for the ease of doing business, and only seven are in the top 100. When looking at two specific indicators – the ease of setting up a business and of dealing with construction permits (two areas that are very important to new entrants adding new capacity or developing electrification business models) – only three sub-Saharan African countries fall in the top 100 rankings for both of these indicators.

Efforts to analyse the specific conditions facing off-grid business developments (the "off grid business indicators", or OBI) paint a sober picture of the situation. According to the OBI report on Africa, the lack of access to financing, corruption and inadequate supply of infrastructure are the most problematic factors for doing business on the continent (Solarenergie, 2014).

Figure 37: Average ranking on sets of Doing Business Indicators



Source: World Bank, 2016.

ANNEX 2: SOLAR PV MANUFACTURING CAPACITY IN AFRICA

With an expanding market for the installation of solar PV systems in Africa, it naturally can be expected that companies which produce solar PV modules locally will emerge and become more common. Already, there are several local and international players with African plants for the **production and assembling of PV modules** (*e.g.*, in Algeria, Mozambique, South Africa, Tunisia and Kenya).[21] In addition to the price reduction of the final product as a consequence of local manufacturing, the solar PV manufacturing industry leads to more jobs for local residents and therefore can improve the economic situation of the region. The African production capacity is not limited to PV modules, as there also are several companies **manufacturing inverters** in South Africa,[22] and more factories are planned (*e.g.*, by ABB, Germany's SMA and Sungrow).

As seen throughout the report, Africa is one of the regions around the globe where off-grid solar PV solutions are attractive due to the lack of infrastructure. Accordingly, companies which offer products for off-grid power also are starting to manufacture their systems locally, with some small factories and workshops **assembling pico PV products** (*e.g.*, Fosera in Mozambique[23] and Ezylight in South Africa).

Table 7 shows an excerpt of manufacturing plants located in Africa with information on the annual production capacity, if available. The sources used can be found below the table.

TABLE 7: PV MODULE ASSEMBLY PLANTS IN AFRICA

Country	Name	Annual capacity	In operation since	Source(s)
Algeria	Condor	50 MW	Oct. 2013	1
Algeria	Rouiba Eclairage	116 MW	Under construction	2
Algeria	ALPV	12 MW	2010	3
Egypt	Sunprism	15 MW	2005	4
Ethiopia	Ethiopian Power Engineering Industries	20 MW	2012/2013	5
Kenya	Ubbink East Africa	8 MW	2009	6
Morocco	Droben	5 MW	2009	7, 8
Morocco	Cleanergy	15 MW	2010	9, 10
Mozambique	FUNAE	5 MW	Nov. 2013	11
Nigeria	NASENI/Karshi	7.5 MW	2011	12
Nigeria	Sokoto/JvG Thoma	10 MW	2013/2014	13
South Africa	ARTsolar	70 MW	2012	14
South Africa	Ezylight	-	-	15
South Africa	Setsolar	-	2007	16
South Africa	Solairedirect Technologies	90 MW	2009	17
South Africa	JA Solar, Powerway	150 MW	Planned	18
Tunisia	Aurasol	-	2010	19
Tunisia	Ifrisol	20 MW	-	20
Tunisia	NR-Sol	25 MW	Dec. 2011	21
Tunisia	Green Panel Technology Jurawatt Tunis SA	30 MW	May/June 2014	22, 23

21 ENF Solar lists 11 companies, 5 of which are in South Africa. There are approximately 3 plants in Algeria.

22 See SAPVIA (2013): The localization potential of photovoltaics (PV) and a strategy to support large scale roll-out in Africa, and also http://www.pv-magazine.com/news/details/beitrag/south-africa-set-for-more-local-pv-manufacturing_100014503/#axzz316qk5ImB

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ABBREVIATIONS

AC	Alternating current
AfDB	African Development Bank
Ah	Amp-hour
BoS	Balance of system
CAPEX	Capital expenditure
CO_2	Carbon dioxide
CSP	Concentrating solar power
DC	Direct current
DOE	Department of Energy
DT	Tunisian dinar
ECREEE	ECOWAS Centre for Renewable Energy and Energy Efficiency
EPC	Engineering, procurement and construction
ESCO	Energy service company
FiT	Feed-in-tariff
FNME	National Energy Management Fund
GIZ	German International Cooperation Agency (Gesellschaft für Internationale Zusammenarbeit)
GMG	Green mini-grids
IFC	International Finance Corporation
GW	Gigawatt
IPP	Independent power producer
IRENA	International Renewable Energy Agency
IRP	Integrated resource plan
IRR	Internal rate of return
kW	Kilowatt
LCOE	Levelised cost of electricity
LED	Light-emitting diode
Li-ion	Lithium-ion
LMCP	Last Mile Connectivity Project
MCC	Millennium Challenge Corporation
MDP	Market Development Program
MW	Megawatt
NAMA	Nationally Appropriate Mitigation Action
NGP	New Generation Power
NREA	New and Renewable Energy Authority
OBI	Off-grid business indicators
OECD	Organisation for Economic Co-operation and Development
PO	Partner organisations
PPA	Power purchase agreement
PPIAF	Public-Private Infrastructure Advisory Facility
REA	Rural Energy Agency
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
SEFA	Sustainable Energy Fund for Africa
SERP	Scaling-up Renewable Energy Program

SHS	Solar home system
SIDA	Swedish International Development Cooperation Agency
SWER	Single Wire Earthing Return
TPES	Total primary energy supply
TOE	Tonne of oil equivalent
TSP	Tunisian Solar Plan
TWh	Terawatt-hour
USD	United States dollar
V	Volt
VAT	Value-added tax
VSPP	Very small power producers
W	Watt

IRENA
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